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DEVELOPMENT OF A DIRIGIBLE BOMB

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ABSTRACT

This report is concerned exclusively with the wind tunnel tests which have been conducted at M. I. T. in connection with the development of a high-angle dirigible bomb.

In Section I the research done previous to October 15, 1942, is summarized. The ballistic coefficients and other aerodynamic data for a tentative final cruciform fin model dirigible bomb are included (see Appendix II.A.).

Section II deals with a series of tests designed to measure the aerodynamic roll torque developed by a cruciform fin structure bomb in combined pitch and yaw. It was found that for adequate roll control the present static aileron driving torque will have to be increased by at least a factor of three.

As a possible means of eliminating the aerodynamic roll torques inherent in a cruciform fin structure, a shroud model high-angle dirigible bomb with cylindrical symmetry about its longitudinal axis was developed. Section III gives the results of wind tunnel tests on a shrouded dirigible bomb.

INTRODUCTION

During the past fifteen years, great improvements have been made in the fields of bombers and bombsights. Bombs themselves, however, have been changed very little. Theoretical trajectories can be computed on the basis of the aerodynamic characteristics of a bomb as determined from wind tunnel tests. In practice, though, such variables as asymmetries in the bomb's construction, undetermined atmospheric conditions in the course of its flight, and variations in the attitude of the bomb at the instant of release from the bomber lead to erratic deviations from the calculated trajectory. Moreover, there is the additional consideration of obtaining hits on a moving target, e.g., a maneuvering ship at sea.

Two solutions to these difficulties, and thereby means for converting misses into "near misses" or into hits on stationary and mobile targets, have been suggested. The obvious one is to bomb from low altitudes as in dive bombing. The other, and more desirable, one is to control the flight of the bomb after it has been released from the bomber. Controllable or dirigible bombs can be classified roughly in two groups, low-angle or glide and high-angle bombs, depending upon the angle at which the bomb strikes the target.

The purpose of the wind tunnel research program carried on at M. I. T. was to design the fin and control surfaces for a high-angle dirigible bomb. In addition, low velocity (40 to 150 m.p.h.) data on the ballistic coefficients of the complete models were obtained. From these data theoretical calculations of the trajectories with control exercised to deviate the bomb from its normal free-fall trajectory were made. The performance of the high-angle dirigible bombs, designed on the basis of the wind tunnel tests, in free flight and at high velocities was checked by actual drop tests.

SECTION I. RESEARCH PREVIOUS TO OCTOBER 15, 1942.

The first wind tunnel tests made on a high-angle dirigible bomb at M. I. T. were conducted to determine the practicality of this type missile (see Section III, First Progress Report). In this connection, measurements were made to check Dryden's results (see Dryden's report, dated February, 1927, summarizing a program of research in bomb ballistics for the Ordnance Department of the Army carried on from 1918 to 1926 at the Bureau of Standards) and to arrive at a tentative fin and control surface design for a dirigible bomb. A half-scale wooden model of the Army M44 1000 lb. demolition bomb was tested in the 5 ft. circular wind tunnel of the Guggenheim Aeronautics Laboratory at M. I. T. Three-component data, C_L, C_D and $C_{M_{CG}}$, obtained on the standard Army Loring fin design were in good agreement with Dryden's results which had been used for preliminary trajectory calculations. In an attempt to increase the available lift, and thereby the maneuverability, and to facilitate the introduction of control surfaces a second fin structure (see Fig. 16, First Progress Report) of the flat-plate cruciform type was also tested. This set of fins was 3" longer than the standard Army M44 fins, the width being equal to the diagonal of the square prism enclosing the cylindrical portion of the bomb case, i.e., width = $\sqrt{2}$ X maximum diameter of bomb case. An elevator surface extending the full width of one of the fins was introduced at its trailing edge. It was found (see Fig. 20, First Progress Report) that the negative lift of the elevator resulted in trim values of C_L and C_D which were essentially the same as those obtained from Dryden's report and used in the preliminary computations. Thus while it was verified that a high-angle bomb could be controlled, the problem of improving the lift characteristics of such a missile remained.

To increase the available lift, the horizontal fin was lengthened by extending it forward along the sides of the bomb case to the beginning of the nose ogive (see Fig. 1, Second Progress Report). Lift, drag, and pitching moment data obtained in the 5 ft. wind tunnel on a half-scale model of the M-44 bomb with this so-called "long sideburn" fin design indicated that for angles of attack greater than 10 degrees, C_L was approximately 40 per cent greater than that for the standard Loring fin structure (see Fig. 2, Second Progress Report). While the controllability (see Fig. 3, Second Progress Report) for this combination of fin structure and control surface was not ideal, it was decided that it was adequate for preliminary work. A solution of the problem of roll control and stability of the bomb was next sought.

Essentially, a second control surface or set of control surfaces is required if the bomb's trajectory is to be controlled in both range and azimuth. As an alternative, the method of operation of a single set of control surfaces might be made variable. The nature and operation of the second surface depends upon the method which is to be used for controlling the flight of the bomb. Two methods of control, R - Θ and X - Y, were considered (see Section III, Second Progress Report).

In R - Θ control, the range and azimuth of the bomb are corrected by use of a single elevator surface, or pair of surfaces, in the horizontal fin and a pair of aileron surfaces in the vertical fin which control the roll of the bomb about its longitudinal axis. Thus the lift vector which is perpendicular to the velocity vector always lies in the plane of the vertical fin, the direction of the lift vector with respect to a fixed vertical plane being capable of variation at will. To obtain X - Y control one stabilizes the bomb with respect to roll about its longitudinal axis and introduces a rudder into the vertical fin which is identical to the elevator in the horizontal surface. Then since the orientation of the fins is known with respect to a fixed vertical plane one can correct the range and azimuth of the bomb by simultaneous application of the elevator and rudder.

The choice between R - Θ and X - Y control of the bomb's flight depends primarily upon the means used for indicating the corrections to be applied to its trajectory and upon the instrumental difficulties encountered in achieving the control. As originally planned, the high-angle dirigible bomb developed at M. I. T. was to have a television camera mounted in its nose to indicate the necessary corrections. From the transmitted television picture, one would know at all times the roll orientation of the bomb and therefore the roll control to be applied. Thus for a television-equipped bomb, which was the only type considered at that time, the choice between R - θ and X - Y control depended essentially upon the instrumental difficulties involved. Since X - Y control requires roll stability which can only be achieved by use of a gyroscopic or other suitable device involving rather complicated instrumentation, it was temporarily rejected. The three-component wind tunnel data obtained on the half-scale model were directly applicable to a study of R - θ control. It remained to determine the roll characteristics of the bomb with the modified cruciform fin design having an elevator in the horizontal surface and a pair of ailerons in the vertical surface.

Three-dimensional trajectory calculations based on R - θ control of the bomb indicated that the aileron driving torque would be adequate if it yielded a maximum roll acceleration of 90 deg./sec.^{2} at 300 m.p.h. To design the ailerons to meet this specification, it was first thought that it would be necessary to determine the driving torque due to different size ailerons as a function of angle of attack, aileron setting and wind velocity. However, due to the fact that only small corrections need be made to the trajectory of a television-equipped bomb and therefore only small angles of attack will be required, it was decided that wind tunnel measurements made at zero angle of attack would suffice. It should be noted that the airflow over the ailerons is essentially the same at small values of attack angle as at zero.

The actual aileron driving torque acting on the bomb in flight can be closely approximated as the difference between the static roll torque produced by the ailerons and the aerodynamic roll damping torque. Consideration of the magnitude of these two torques (see Section 3.C and Appendix C of Third Progress Report) showed that during the first revolution of the bomb the damping torque is small compared with the static driving torque and can therefore be neglected, R - θ control requiring roll displacements not greater than 50 degrees. This conclusion was borne out by drop tests of 100 lb. practice bombs (see Sec. 4, Third Progress Report). Attempts to measure the static roll torque developed by aileron tabs introduced into the vertical fin at its trailing edge (see Fig. 8, Second Progress Report) on a half-scale model mounted in the 5 ft. tunnel using the 5-wire Prandtl suspension (see Fig. 11, First Progress Report) were unsuccessful due to the low sensitivity of the No. 3 and No. 4 balances. Subsequent measurements were made on the half-scale wooden model mounted so that it was free to rotate about its longitudinal axis, the longitudinal axis being coaxial with the test section of the tunnel, i.e., zero angle of attack. Data obtained from these experiments (see Section 3, Third Progress Report; Section 3, Fifth Progress Report) led to the final design of the ailerons for the television-equipped R - Θ controlled 1000 lb. bomb, as shown in Fig. 2 of the Fifth Progress Report.

To check the roll characteristics of the bomb at angles of attack other than zero, qualitative experiments were conducted in the M. I. T. 5' x 7' wind tunnel on the half-scale wooden model, gimbal-mounted to permit it complete rotational freedom about its center of mass (see Fig. 11 and Section 3.2, Third Progress Report). As was predicted (see Section 3.1, Third Progress Report), the application of the aileron driving torque at finite angles of attack resulted in spinning motion of the bomb or helical trajectory in free flight. Thus, qualitatively the longitudinal axis of the bomb described a cone, the velocity vector being the cone axis. At the same time, the bomb rolled about its longitudinal axis with an angular velocity determined by the aileron driving torque. The angular velocity of the longitudinal axis about the cone was equal to the roll angular velocity.

With the fin and control surface design completed on the basis of wind tunnel measurements, construction work on a full-scale 1000 lb. television-equipped R - 9 controlled bomb was undertaken. For instrumental reasons, a number of changes were made in the shape of the case and the disposition of the elevator control surface. The most significant of these were the division of the elevator into two surfaces and the pivoting of both the elevators and the ailerons 20 per cent of their chord lengths from their leading edges to achieve an aerodynamic balance and thereby reduce the hinge moments (see Fig. 2, Fifth Progress Report). To check the effects of these changes on the aerodynamic properties of the bomb and to obtain data on the overall performance of the completed unit, a series of wind tunnel tests were conducted in the M. I. T. Wright Brothers' Wind Tunnel on the full-scale bomb at a velocity of 150 m.p.h. (see Sections 2 and 3, Fifth Progress Report). For this series of experiments, two different mountings were used. The pitch characteristics of the bomb were studied by permitting the bomb to rotate freely about a transverse axis through the c.g. while roll control was investigated with the bomb free to rotate about its longitudinal axis at zero angle of attack. As a result of these tests, it was decided to modify the fin structure by shortening the sideburns so that they only extended forward to the c.g. of the bomb (designated as Fin B or short sideburns). While this decreased the available lift, it improved the pitch stability and controllability of the bomb. Attempts to control the roll orientation by manipulation of the ailerons indicated that because of the small value of the roll damping torque acting at low angular velocities, rapid deflections of the ailerons with a return to neutral at the time of reversal of the direction of roll were required to maintain a given orientation. Solenoid operation of the ailerons was therefore substituted for the motor control originally designed. Moreover, due to roll asymmetries in the fin structure introduced in the construction of the bomb, it was found necessary to control the roll continuously. As part of the tests with the bomb mounted on the transverse axis, lift, drag, and controllability data were obtained for Fin B and used in subsequent trajectory calculations. These data were later checked for a half-scale model in the 5 ft. wind tunnel. The final aerodynamic design of the 1000 lb. television-equipped F - 9 controlled high-angle dirigible bomb is given in Fig. 2 of the Fifth Progress Report.

At this stage in the development of a high-angle dirigible bomb, the M. I. T. group was requested to consider possible means other than television equipment for indicating the corrections necessary to the bomb's trajectory. In particular, the practicality of a direct sight bomb was to be investigated. Since there is no means for determining the roll orientation of an R - Θ controlled direct sight bomb, the question of R - Θ versus X - Y control was reconsidered.

Wind tunnel tests on the full-scale 1000 lb. television bomb and on a half-scale metal model of it with remotely operated elevators and ailerons and mounted in a gimbal system permitting complete rotational freedom about its center of mass (see movie records) had indicated that continuous roll control was essential. Moreover, the time interval involved in effecting R - Θ control is inherently longer than that required for X - Y control. These facts together with the necessity of automatically stabilizing the roll orientation of a direct sight bomb made it appear advisable to employ X - Y control for all future high-angle dirigible bombs in spite of the instrumental complications involved. A two gyro system consisting of a directional and a rate of turn gyro was therefore developed for the automatic manipulation of the ailerons to stabilize the roll orientation of the bomb (see Section 4, Fifth Progress Report). A laboratory model of this gyro system was tested in the half-scale metal gimbal-mounted model in the 5 ft. wind tunnel and the roll stabilization in pitch found to be adequate (see movie records).

While it was realized that the three-component pitch data thus far obtained were not directly applicable to an X - Y controlled bomb, wind tunnel tests for combined pitch and yaw were postponed until a pilot-plant production model of a 1000 lb. high-angle bomb with cruciform fin structure based on the M. I. T. television-equipped unit had been completed by the Gulf Research and Development Company (see below). In the meantime, further consideration of the technique of direct sight bombing indicated that the lift available in the M. I. T. television bomb would not be adequate for certain applications of it. A series of experiments designed to investigate the effects of widening and lengthening Fin B and separating the lift and control surfaces were therefore conducted in the Wright Brothers' Wind Tunnel on a 3/4-scale wooden model of the M. I. T. 1000 lb. television bomb. The results of these tests which involved the determination of the static pitch characteristics of eight different fin structures are summarized in Section 4 of the Sixth Progress Report.

The Gulf pilot-plant production model of a 1000 lb. high-angle dirigible bomb is shown in Fig. 1. It was designed for the drop-testing of bombs suitable for testing television, target-seeking, direct sight, or any other techniques of dirigible high-angle bombing. The nose and tail ogives of the case were altered from those of the standard Army M-44 bomb to accommodate more readily control equipment. The fin structure is essentially that developed for the M. I. T. 1000 lb. television-equipped R - θ controlled bomb. Fin structure C rather than B was used for the vertical fin to permit easier mounting of the bomb hooks. The Gulf bomb was designed for X - Y control being gyro-stabilized with respect to roll. The rudder control surfaces in the vertical fin are identical with the elevators. Aileron action for roll control is achieved by a solenoid-operated differential deflection of $\pm$ 3 deg. about the neutral position of the two halves of the rudder assembly.

To check the ballistic coefficients and the characteristics in combined pitch and yaw of the Gulf bomb, a special gimbal-mounted full-scale model was tested in the Wright Brothers' Wind Tunnel at a velocity of 150 m.p.h. These tests are described and the results summarized in Section IV of the Gulf Research and Development Company Progress Report of October 15, 1942, entitled "Experimental Investigations in Connection with High-Angle Dirigible Bombs." Since the Gulf bomb represents the tentative final high-angle dirigible cruciform fin model bomb, the experimental results are reproduced graphically here in Figs. 2 - 19. In addition to the graphs in the Gulf Report, four other plots are included. Figs. 16 - 18 represent averages with respect to control surface setting and angle of attack of the two-point (model free in pitch) controllability and ballistic coefficient results given in Figs. 13 - 15. These average values are used in calculating trajectories for the Gulf bomb. Fig. 19 is a plot of the elevator hinge moment at trim versus the corresponding trim value of C_L for the bomb.

The study of the bomb's characteristics in combined pitch and yaw revealed the following facts. The controllability curves for the horizontal and vertical fins remain essentially the same as those for each of them in pitch alone (see Fig. 16). At most the vertical lift force on the bomb in trim in pitch is decreased by 15 per cent when the bomb is simultaneously yawed. Moreover, it was found that the drag force was approximately equal to the sum of the drag forces on the bomb for the horizontal and vertical fins in pitch alone. The most significant result of this portion of the wind tunnel tests on the Gulf bomb was that inherent aerodynamic roll torques of the order of ten times the magnitude of the static aileron driving torque were found to exist when the model was simultaneously pitched and yawed. The present report is chiefly concerned with the results of a study of these roll torques and a possible means of eliminating them by substituting shrouds for the cruciform fin structure.

SECTION II. ROLL TORQUE TESTS

A. MODEL

A specially designed half-scale model of the Gulf high-angle cruciform fin bomb was used for the study of the roll torques developed in combined pitch and yaw. Details of the model are shown schematically in Fig. 20. The case which was hollow and made of wood was divided into two parts, nose and tail, at a point approximately 1" forward of the c.g. of the bomb. These two "halves" were then mounted on a 3/4" steel rod with approximately 1/32" clearance between them, the rod constituting the longitudinal axis of the bomb. The nose half was fixed to the rod while the rear portion was free to rotate on ball bearings. Detachable 1/8" dural fins with the standard Gulf control surfaces were mounted in slots milled in the tail portion of the case. The rear half was coupled to the fixed nose portion via a ball bearing mounted indexed dural disc with radial slots milled at 10 deg. intervals around its circumference and a resistance wire strain gauge on a cantilever beam fixed to the front half. Thus, the tail half of the model having been mechanically balanced, aerodynamic roll torques developed by the fin structure as a function of roll angle could be obtained directly from the strain gauge readings. The roll orientation of the fin structure was varied in 10 deg. intervals by means of a key fitting the radial slots in the indexed dural disc.

The method used for mounting the model in the wind tunnel is shown schematically in Fig. 21. The steel rod constituting the longitudinal axis of the model was supported by two vertical rods telescoping into steel tubes which were fastened to the movable portion of a channel frame resting on the floor of the tunnel. By varying the heights of the vertical supports it was possible to vary the attitude of the model in pitch from - 15 deg. to + 15 deg. The yaw attitude was varied by rotating the portion of the channel frame carrying the axis rod supports about a vertical pivot axis midway between the supports (yaw range = $\pm$ 20 deg.). Thus it was possible to vary the pitch and yaw of the model independently or simultaneously.

B. EXPERIMENTAL PROCEDURE AND TESTS

All of the roll torque tests were conducted in the M. I. T. 5 ft. circular wind tunnel. They were made at velocities of 40 and 50 m.p.h., the lower velocity being used for those configurations which developed excessively high values of roll torque beyond the range of the strain gauge. A symmetrical fin structure of type B (see Fig. 1) was used for all the tests, i.e., both the horizontal and vertical fins were type B. This fin structure rather than the asymmetrical one of the Gulf high-angle bomb having horizontal Fin B and vertical Fin C was tested for two reasons. The measurements on the full-scale gimbal-mounted Gulf model in the Wright

Brothers' Tunnel had indicated that roll torques of the order of ten times the magnitude of the available aileron driving torque were developed in combined pitch and yaw. It was therefore evident that the asymmetrical fin structure was unsuitable for an X - Y controlled bomb requiring corrections to its trajectory in both range and azimuth, it being impractical if not impossible to increase the aileron torque by a factor of ten. Moreover, if the cruciform fin dirigible bomb were to be used for direct sight bombing, all of the lift for Fin B would be required. Consequently, a symmetrical fin structure of type B was selected for the roll torque tests.

A typical test run consisted of the following. The angle of attack was first adjusted by pitching and (or) yawing the model by means of the tunnel mounting described above. For this particular attitude the roll torque developed was then measured as a function of the roll angle which was varied by steps of 10 deg. for ± 60 deg. of roll. Zero roll angle was taken to be the orientation of the fins for pitch and yaw trim of the bomb for the selected attitude.

Before investigating the roll torques acting on the bomb, the static aileron driving torque at zero pitch, yaw, and roll angles was measured. The horizontal control surfaces were used as ailerons to minimize the effect of the vertical support rods on the airflow over the model. In addition to the standard aileron action of ± 3 deg., data were obtained for differential deflections of ± 5 deg. and ± 10 deg.

Roll torque measurements were made for pitch and yaw alone and for a number of combinations of pitch and yaw. Most of the data were obtained for negative pitch angles to minimize the effect of the vertical supports. For each attitude, data were taken for zero settings of the control surfaces and also for trim value settings as given for Fin B in Fig. 16. Thus an attempt was made to separate the effects of the fins and the control surfaces on the development of roll torques.

C. RESULTS AND DISCUSSION

The results of the roll torque tests are summarized graphically in Figs. 22 - 28. The following sign convention is used for the angular displacements of the model. Pitch is positive for "nose-up", i.e., sail rather than dive. Viewing the model from above, clockwise rotations about a vertical axis through the c.g. constitute positive yaw. A positive roll angle is a clockwise rotation about the longitudinal axis looking from the tail toward the nose of the bomb.

Fig. 22 gives the static aileron driving torque as a function of the differential deflection of a set of the control surfaces. While the data were obtained on a half-scale model at a velocity of 50 m.p.h., the results are for convenience of comparison with drop-test data plotted for a full-scale model at a velocity of 150 m.p.h. It will be noted that the static aileron driving torque is a linear function of the differential deflection for the range covered in the measurements and that for the standard ± 3 deg. it is equal to 2.4 lb.-ft. (full-scale, 150 m.p.h.). Since one is primarily interested in counteracting any inherent roll torques with an equal or greater and opposite aileron driving torque to maintain control of the bomb, the static aileron driving torque for a ± 3 deg. differential deflection was chosen as the unit of roll torque. Moreover, this unit is independent of the scale of the model and the test velocity.

Measurements of the roll torques developed with zero settings of the control surfaces showed only minor differences between the two sets of data. With trim settings, the roll torques were slightly less at zero roll orientation. From this it was concluded that the fin rather than the control surfaces were responsible for the inherent roll torques which were measured. Since in practice one is only concerned with the behavior of the bomb in the neighborhood of trim, the results of the "zero setting" measurements are not given here.

Fig. 23 represents a plot in the pitch-yaw quadrants of the roll torques measured at zero roll orientation, i.e., pitch and yaw trim. An attempt has been made to draw in the contours in the negative pitch and positive yaw quadrant. While the gyro-stabilizing unit is designed to maintain a zero roll orientation of the bomb, the "tightness" of the roll control it exercises is limited to approximately ± 5 deg. of roll. Fig. 24 gives the maximum values of roll torque encountered in the range of ± 10 deg. of roll, again plotted in the pitch-yaw quadrants. Figs. 25 - 28 represent the types of curves obtained for the roll torque as a function of roll angle for particular attitudes of the bomb. From an examination of these one can determine the nature of the stability of a given roll equilibrium position.

To offer at least a qualitative explanation of the measured roll torques, one must account for the results given in Fig. 23 and the type stability possessed by the bomb (Figs. 25 - 28). Thus in pitch and yaw alone, it was found that the bomb was in roll equilibrium at zero roll orientation. Moreover, these roll equilibrium positions are stable as indicated by the negative slope of the roll torque versus roll angle curves (see Figs. 25 and 26). For attitudes of equal pitch and yaw displacements, zero roll angle also constitutes a roll equilibrium orientation. In this case, however, the equilibrium is metastable as shown by the positive slope of the roll torque-roll angle plot (see Fig. 27). For attitudes of unequal pitch and yaw the bomb is not in roll equilibrium at zero roll angle (see Fig. 28).

Remembering that the roll torques developed are due primarily to the fin and not the control surfaces, the results can be explained qualitatively on the basis of the maximum cross-sectional area theorem and asymmetrical airflow over the two halves of a given fin surface. By the maximum cross-sectional area theorem is meant the fact that a rectangular flat plate free to rotate about its "longitudinal axis," that axis lying in the plane of the plate along the center line parallel to its longer dimension, will if placed in a wind-stream rotate about this axis until it presents a maximum cross-sectional area to the wind. This condition is satisfied when the flat plate is tangent to the cone of which its longitudinal axis is an element and the wind velocity vector the axis. Also since it is only in this orientation that the center of pressure lies on the pivot axis of the plate, it is a stable configuration, an aerodynamic restoring torque being developed if the plate is rotated slightly out of the tangent plane to the cone.

Considering the cruciform fin structure as being composed of two flat plates set at right angles with their longitudinal axes collinear with the longitudinal axis of the bomb case, we would then predict that in pitch and yaw alone the bomb would be in stable roll equilibrium at zero roll angle. This is exactly what the roll torque tests proved (see Figs. 23, 25, 26).

For simultaneous pitch and yaw, the explanation of the results is somewhat more complicated. Let us take up the case of equal pitch and yaw first. At zero roll angle in equal pitch and yaw each of the fin surfaces makes an angle of 45 deg. with the tangent plane to the cone. Therefore, the restoring torques acting on them are equal but opposite in sign. Moreover, any asymmetries in airflow due to downwash from the body and other fin surface over the two halves of a given fin will be counterbalanced by an equal and opposite effect on the other surface. Zero roll angle should then be a roll equilibrium position for equal pitch and yaw. This same conclusion can be reached from symmetry considerations. Thus at zero roll angle in equal pitch and yaw, the plane determined by the longitudinal axis of the bomb and the wind velocity vector constitutes a reflection plane of symmetry for the bomb. The net lift vector acting on the bomb must therefore lie in this plane and hence the roll torque be zero. However, since there will be an unbalance of the restoring torques on the two fin surfaces and of the effects of asymmetries in airflow giving rise to roll torques in the same direction as roll displacements from the zero orientation, the roll equilibrium found for equal pitch and yaw should not be stable. Unstable roll equilibrium for equal pitch and yaw was observed (see Fig. 27). In addition, it was found that roll orientations of $\pm$ 45 deg. were stable roll equilibrium positions which is what the maximum cross-sectional area theorem would predict.

At zero roll angle for attitudes of unequal pitch and yaw (both different from zero) the two fin surfaces make unequal angles to the tangent plane to the cone. Essentially, the problem is the same as that for roll angles different from zero at equal pitch and yaw. Thus an inherent aerodynamic roll torque will exist at zero roll orientation. The sign and magnitude of this torque will depend upon the signs and relative magnitudes of the pitch and yaw for the attitude under consideration. The results of the measurements for the negative pitch and positive yaw quadrant are given in Fig. 23. Symmetry conditions permit one to predict the signs of the roll torques for the other quadrants, the magnitudes being the same.

D. CONCLUSIONS

From Figs. 23 and 24 it is evident that at least three units (safety factor of 1.5) of aileron driving torque are required to maintain roll control of an X - Y controlled high-angle dirigible bomb with symmetrical type B cruciform fin structure, the pitch and yaw angles being limited to $\pm$ 15 deg. and the gyro-stabilizer assumed to maintain the roll orientation within $\pm$ 10 deg. of zero. In practice, it is extremely difficult to increase the available aileron driving torque by a factor of three. The necessary increase in the effective area of the ailerons and (or) the larger differential deflections needed raises the power requirements excessively and may cause interference with the rudder control system. A possible means of eliminating the inherent roll torques by replacing the curciform fin structure with cylindrical shrouds giving cylindrical symmetry about the longitudinal axis of the bomb was therefore considered.

SECTION III. SHROUDED HIGH-ANGLE DIRIGIBLE BOMB

A. FINAL SHROUD MODEL

1. MODEL

The general form of the shrouded high-angle bomb developed at M. I. T. in collaboration with members of the staff of the Gulf Research and Development Company is illustrated in Figs. 29 - 31 which are photographs of the model used for the wind tunnel tests. The case of the bomb tested was a half-scale sheet aluminum model of that used for the 1000 lb. Gulf high-angle bomb (see Fig. 1). Three cylindrical shrouds mounted coaxial with the case and functionally designated as the lift shroud (L.S.), stability shroud (S.S.) and control shroud (C.S.) replaced the flat plate fins and rudder and elevator control surfaces of the cruciform model high-angle bomb. The disposition and half-scale dimensions of these shrouds are shown in Fig. 32. The diameter of the lift and stability shrouds is approximately equal to the width of the cruciform type fins. The lift shroud was mounted on eight studs symmetrically spaced in pairs at intervals of 90 deg. around the cylindrical portion of the case while a single transverse diametrical rod supported the stability shroud. Control of the pitch angle of the bomb was achieved through varying the angle of attack of the control shroud by rotation about a transverse diametrical pivot axis (see Fig. 31). In an attempt to attain an aerodynamic balance and thereby reduce the hinge moments, the pivot axis was located back of the leading edge of the control shroud. The model was equipped with two transverse 3/8" steel rods, one passing through the c.g. of the bomb and the other 10" to the rear of it, to facilitate mounting it in the wind tunnel.

2. EXPERIMENTAL PROCEDURE AND TESTS.

Three-component data were obtained for the half-scale shroud model in the M. I. T. 5 ft. circular wind tunnel at a velocity of 40 m.p.h. The standard Prandtl 5-wire suspension was used, pitching moments being obtained directly about the transverse rod passing through the c.g. of the bomb. At the same time hinge moment data were recorded for the control shroud. The pivot axis was free to rotate in ball bearings and angular settings were made by adjusting a turnbuckle coupled to a cantilever beam which was fixed to the pivot axis and on which was mounted a resistance wire strain gauge. Hinge moments were obtained for two different positions of the pivot axis, one 25 per cent and the other 40 per cent of the length of the control shroud back of its leading edge.

3. RESULTS AND DISCUSSION

The results of the measurements made on the half-scale shroud model are summarized graphically in Figs. 33 - 40. A comparison of Figs. 33 - 37 with data obtained for the cruciform Fin B (see Figs. 2, 4, 6, 8, 9, and 11) reveals the following. The controllability for small settings of the control surface is better for the shroud than for the cruciform model, the slope of the shroud controllability curve being very nearly constant. The pitch stability of the shroud model is considerably greater for small angles of attack and is approximately constant for all attitudes. The available lift for the two models is about the same, C_L being equal to 1.0 for a trim angle of attack of 15 deg. While the drag is roughly twice as great on the shroud as on the cruciform bomb, this fact should be advantageous in that it will increase the time of flight of the bomb and thereby the time available for applying corrections to its trajectory.

Figs. 38 and 39 give the hinge moment data obtained for the control shroud. In Fig. 40 the corresponding trim values of hinge moment for a full-scale model at 150 m.p.h. are plotted as a function of the lift coefficient of the bomb. The results for the cruciform Fin B (see Fig. 19) are reproduced here to the same scale for comparison purposes. From Fig. 40 it is evident that there is no unique neutral or aerodynamic balance pivot axis for the control shroud. Moreover, the excessively high values of hinge moments encountered for any given pivot axis rule out the possibility of varying the angle of attack of a shroud to control the attitude of a high-angle dirigible bomb.

It should be noted that due to the cylindrical symmetry about the longitudinal axis the three-component data for the shroud model are applicable to an X - Y controlled bomb of this type. Thus, having gyro-stabilized the bomb with respect to roll, the control shroud would be simultaneously rotated about two orthogonal pivot axes to give the bomb both pitch and yaw. Two small flat-plate solenoid-operated aileron tabs mounted to the rear of the lift shroud could be used to counteract roll torques due to constructional asymmetries and transients during the time of application of control.

4. CONCLUSIONS

While the shroud model is superior to the cruciform fin bomb, the excessive power requirements make it impossible to employ a shroud as the control surface. As a possible solution to this difficulty, it has been suggested that the control shroud be eliminated and the stability shroud replaced by a square (or octagonal) flat-plate structure resembling the Loring fin design for the standard 1000 lb. Army M-44 bomb. Balanced rudders and elevators would then be introduced into the trailing edges of the square. Thus it would be possible to minimize the control surface hinge moments yet approximate cylindrical symmetry and thereby also minimize roll torques developed for attitudes of simultaneous pitch and yaw.

B. PRELIMINARY TESTS

A considerable number of wind tunnel tests were run at M. I. T. in connection with the shrouded high-angle dirigible bomb. The object of this work was to develop a shroud model possessing the following aerodynamic characteristics as compared with the cruciform fin structure bomb:

(1) Improved controllability and pitch stability at small angles of attack.

(2) Available lift equal to that for cruciform Fin B.

1. MODEL

The half-scale sheet aluminum bomb case described above (see Section III. A. 1) was used for all the tests. In some of the earlier work a single 9" diameter shroud was used as the tail structure. For such configurations this tail shroud acted both as stabilizing and control surface and hence was designated as the control stability shroud (C.S.S.). The preliminary work also included an investigation of the effect of a spoiler on the pitch stability of the two shroud (L.S. and C.S.S.) configuration. The spoiler used consisted of a sheet aluminum sleeve snugly fitting around the cylindrical portion of the bomb case and capable of being slid forward to project over the nose ogive (see Fig. 41).

2. EXPERIMENTAL PROCEDURE AND TESTS

The preliminary investigations of a shrouded high-angle bomb consisted of obtaining three-component data for various configurations. All of these tests were conducted in the M. I. T. 5 ft. circular wind tunnel at a velocity of 40 or 50 m.p.h. The Prandtl 5-wire suspension was used for all configurations.

After measurements had been made on the bomb case and the case + L.S., the characteristics of two-shroud configurations were investigated. In this connection, lift shrouds of two different diameters, 12 3/4" and 11 3/4", and two control stability shrouds, 9" in diameter and 4" and 6" long, were used.

The effect of the spoiler on the stability of the two-shroud model, 7" x 12 3/4" L.S. and 6" x 9" C.S.S., was then tested. Next the properties of a two-shroud bomb with the diameter of the C.S.S. equal to the diameter of the L.S. were determined. Finally, the characteristics of sixteen different three-shroud (L.S., S.S. and C.S.) configurations including the use of a 14 1/2" diameter L.S. were investigated. As a check on their aerodynamic properties, three-component measurements were made on seven different shrouds: 7" x 12 3/4", 5" x 12 3/4", 7" x 11 3/4", 5" x 11 3/4", 4" x 9", 3" x 9", and 4" x 7".

3. RESULTS AND DISCUSSION

It was found that due to the asymmetrical drag on the lift shroud, the lower half of which is in the downwash of the bomb case, the two-shroud configurations with a 9" diameter C.S.S. were unstable for angles of attack less than 10 deg. The plots of pitching moment coefficient versus angle of attack were pronounced cubics giving three intercepts for a zero setting of the C.S.S. Displacing the lift shroud rearward a total of 3" did not appreciably improve the pitch stability of the model. While the use of the spoiler eliminated the pitch instability, possible microphonic disturbances at high velocities render it undesirable. Increasing the diameter of the C.S.S. improved the pitch stability but gave poor controllability. The three-shroud model permitted one to vary the lift, stability and controllability by varying the relative sizes and disposition of the L.S., S.S., and C.S. The final shroud model described in Section III. A. represents the best compromise of lift, stability, and controllability characteristics. Lift data indicated that decreasing the diameter of the L.S. from 12 3/4" to 11 3/4" would lower the available lift by 20 per cent while increasing to 14 1/2" would raise it by about 40 per cent.

The results for only that portion of the preliminary work which might aid in the design of a square flat-plate tail structure for the shrouded high-angle dirigible bomb are included in this report. Figs. 42 - 44 represent the data for the bomb case while Figs. 45 - 47 give the results for the case + 7" x 12 3/4" L.S. Lift, drag and pitching moment data for five different shrouds are given in Figs. 48 - 50.

SUMMARY AND CONCLUSIONS

On the basis of low velocity wind tunnel tests conducted at M. I. T., two tentative designs for a high-angle dirigible bomb have been evolved, one possessing a symmetrical type B cruciform fin structure (see Fig. 1) and the other a shrouded model (see Figs. 29 - 32). If the cruciform model is to be used as an X - Y controlled bomb, the available aileron driving torque must be increased by at least a factor of three to maintain roll control in simultaneous pitch and yaw. While the use of a shroud as a lift surface eliminates the inherent aerodynamic roll torques developed by the cruciform fin structure, a redesign of the tail assembly of the present shroud model is required to reduce the control surface hinge moments before it can be employed as a high-angle dirigible bomb.

Future wind tunnel work in connection with the development of a high-angle dirigible bomb and the type model, cruciform or shroud, finally selected depends upon the over-all size specifications dictated by the U. S. Army. The cruciform fin bomb can be carried in the bomb racks of most present Army bombers and therefore will be chosen as the final model if it is required that the standard racks be used. On the other hand, if modified racks are used, the shrouded high-angle bomb will be selected and wind tunnel tests should be conducted to complete the redesign of the tail structure. Modified bomb racks will be needed since the cross-sectional area occupied by the shroud model is greater than for the cruciform fin structure, the cruciform fins being the diagonals of the square prism enclosing the cylindrical portion of the bomb case.

SEVENTH PROGRESS REPORT:

Written and submitted by:

J. F. Hutzenlaub

Approved by:

B. E. Warren

April 15, 1943.

APPENDIX I: TERMINOLOGY

With the exception of the roll torque tests, all of the quantitative measurements were made with the model in pitch alone, i.e., three-component data were obtained. The terms pitch, yaw and roll as applied to the roll torque tests are defined in Section II.C. The terminology used in the discussion of the wind tunnel tests of the pitch characteristics of a high-angle bomb is as follows:

Lift Coefficient, C_L: The lift coefficient is so defined that the lift, or cross wind, force, L, acting on the bomb is given by,

$$L = C_L \times \frac{1}{2} \rho V^2 \times A$$

where A is the cross-sectional area in square feet of the cylindrical portion of the bomb body, ρ is the density of the air in slugs/cubic ft., V is the wind velocity in ft./sec., and L is in pounds.

Drag Coefficient, C_D: The drag coefficient is so defined that the drag force, D, acting on the bomb is given by,

$$D = C_D \times \frac{1}{2} \rho V^2 \times A$$

ρ, A, and V being defined as for C_L, and D being given in pounds.

Angle of Attack, α: α is defined as the angle which the longitudinal axis of the bomb makes with the wind direction. For three-component measurements, the pitch angle is identical with the angle of attack.

Pitching Moment Coefficient, $C_{M_{CG}}$: The pitching moment coefficient is so defined that the torque or moment about the c.g. of the bomb is given by:

$$M_{CG} = C_{M_{CG}} \times \frac{1}{2} \rho V^2 \times A \times \ell$$

where ρ, A, and V are defined as for C_L, ℓ is the scale of the model (expressed in feet), and M_{CG} is in pound-feet.

Trim: The bomb is said to be trimmed or in trim when it is in rotational equilibrium, i.e., when $C_{M_{CG}} = 0$.

Controllability: Controllability is defined as the slope of the curve of trim angle of attack versus control surface setting or angle, δ. For an ideal bomb, the controllability would be independent of α.

Stability: Stability is defined as the slope of the curve of pitching moment coefficient vs. angle of attack at trim.

35

APPENDIX II. A. GULF CRUCIFORM HIGH-ANGLE BOMB:
FIGS. 1 - 19.

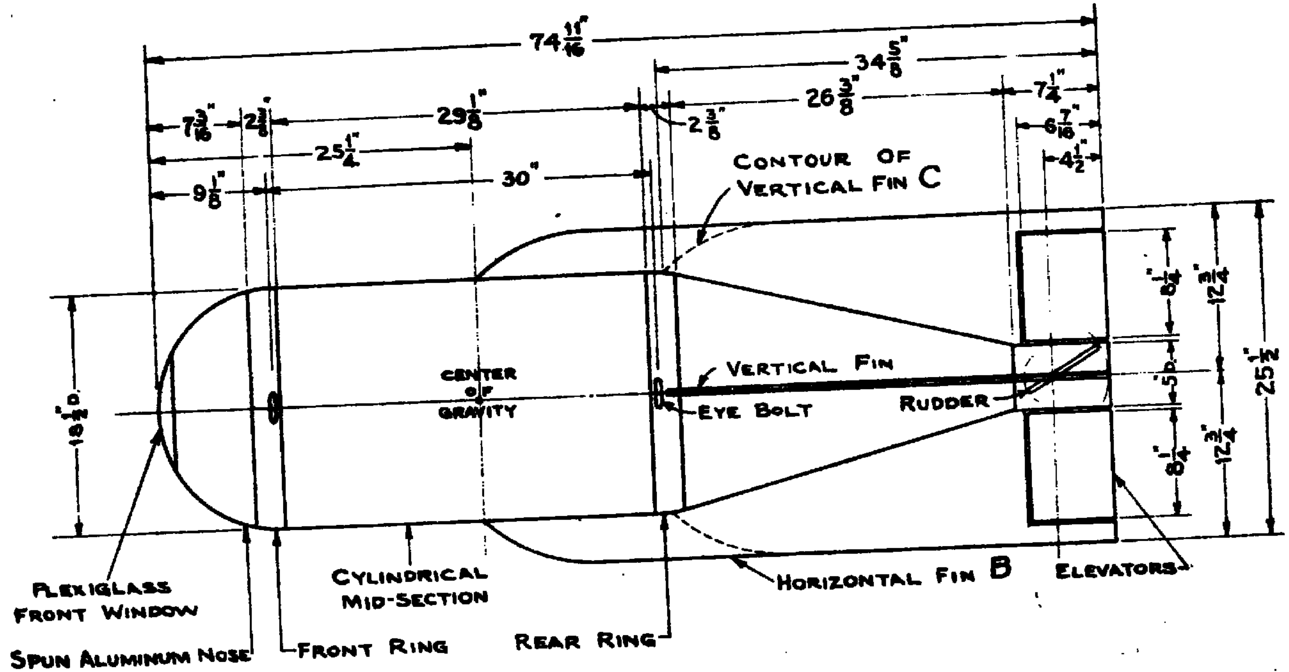


Fig. 21 Top View Of Gulf High Angle Bomb

CRUCIFORM SYMBOLS

SYMBOL	δ (°)
⊙	0
◬	1
⊡	2
▼	4
┼	6
◭	8
◬	10
✕	15
●	20
▲	25
■	30

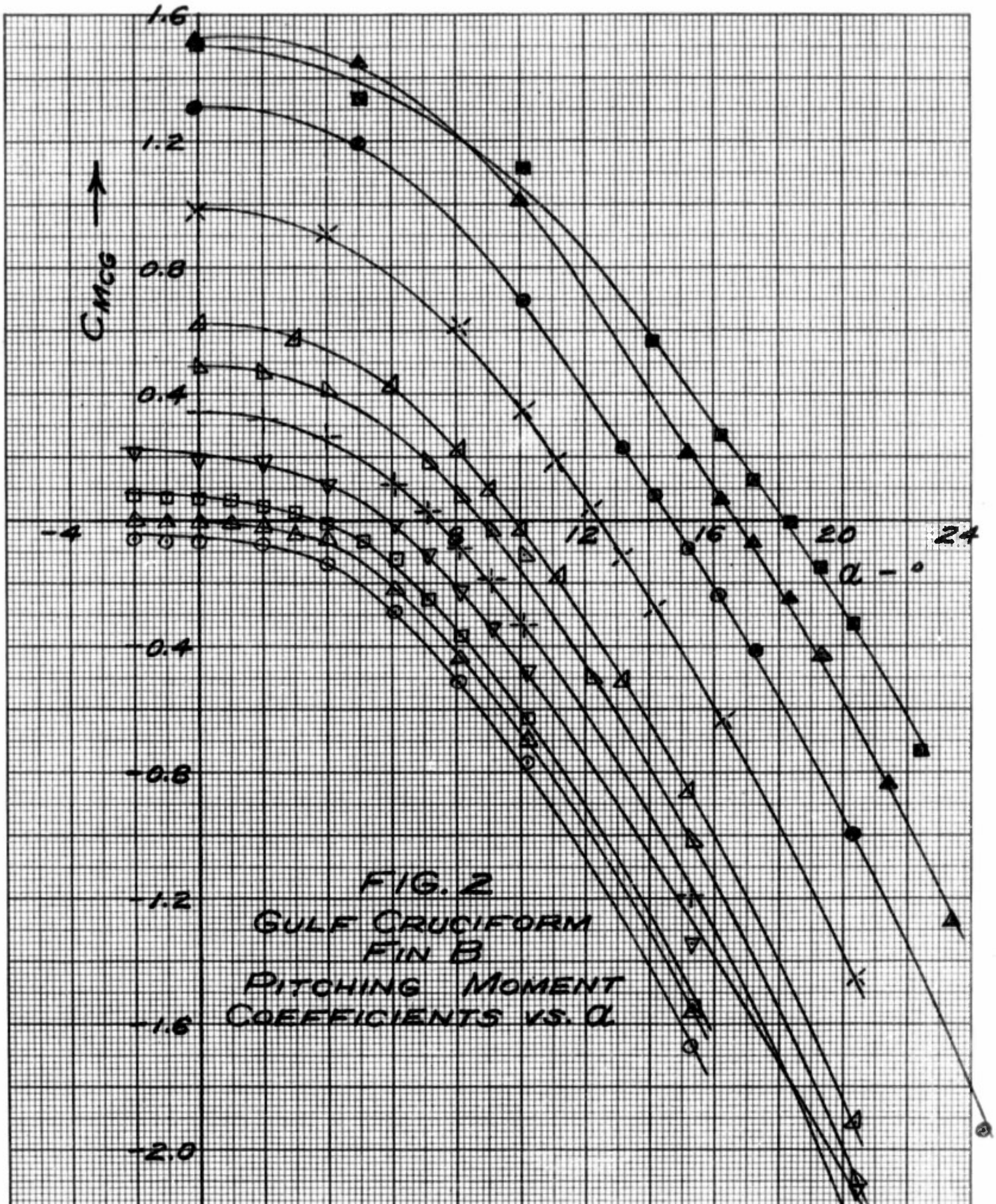
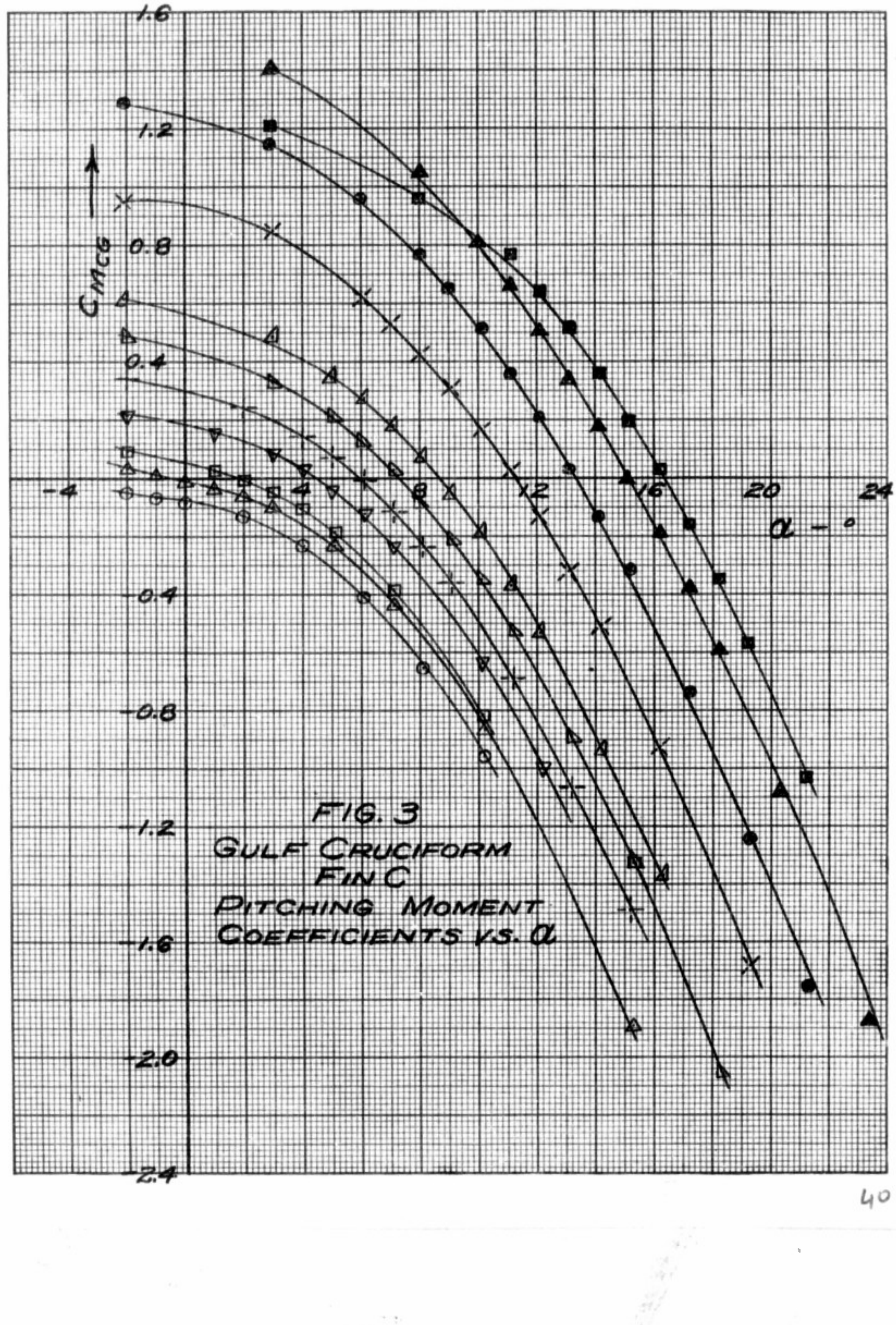


FIG. 2
GULF CRUCIFORM
FIN B
PITCHING MOMENT
COEFFICIENTS VS. α


1.6
1.2
0.8
0.4
-0.4
-0.8
-1.2
-1.6
-2.0
-2.4
-4
4
8
12
16
20
24
$C_{M_{CG}}$
α - °
FIG. 3
GULF CRUCIFORM
FIN C
PITCHING MOMENT
COEFFICIENTS VS. α

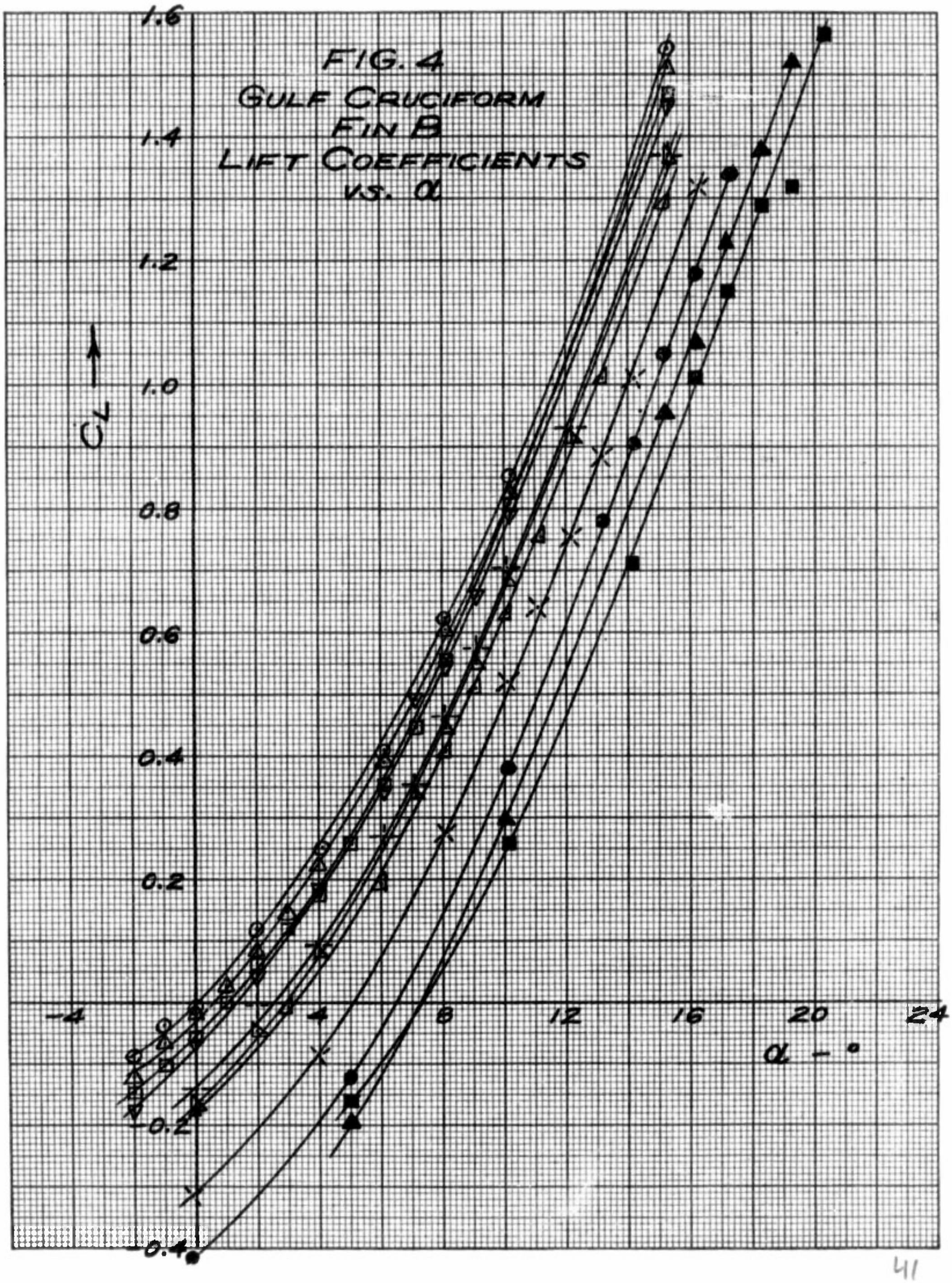


FIG. 4
GULF CRUCIFORM
FIN B
LIFT COEFFICIENTS
VS. α
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4
CL
-4
4
8
12
16
20
24
α - °

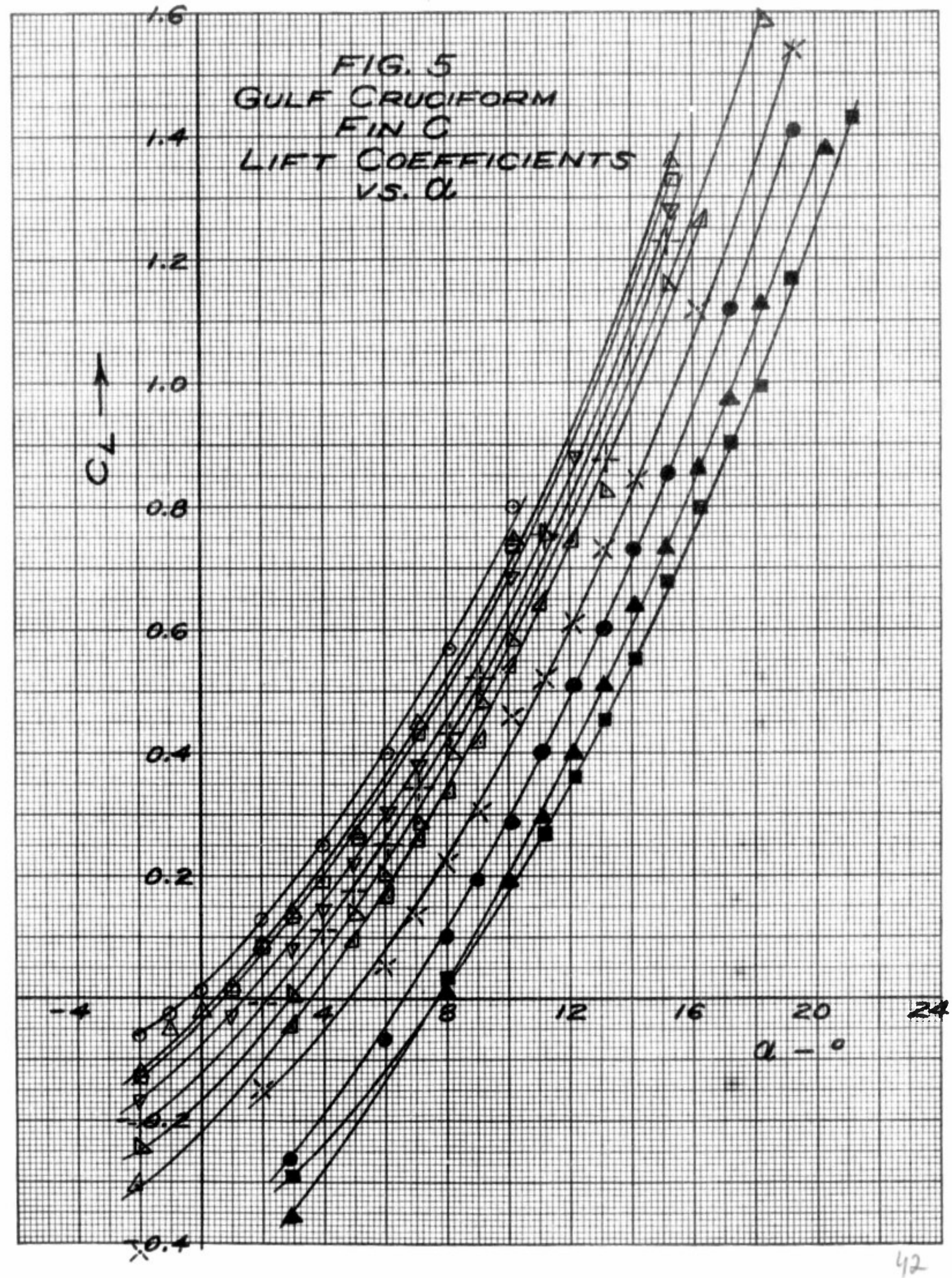


FIG. 5
GULF CRUCIFORM
FIN C
LIFT COEFFICIENTS
VS. α
C_L
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4
-4
4
8
12
16
20
24
α – °

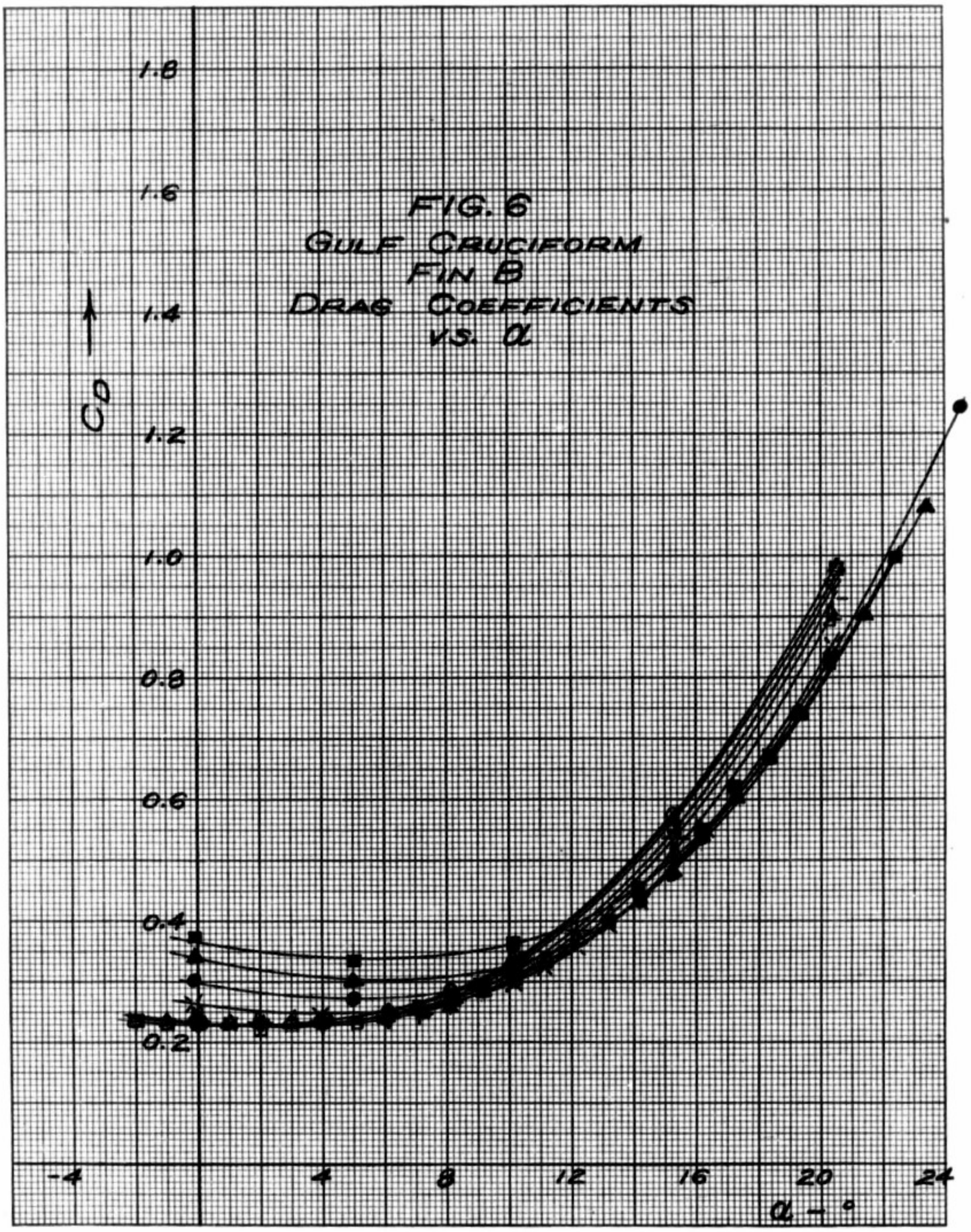


FIG. 6
GULF CRUCIFORM
FIN B
DRAG COEFFICIENTS
VS. α
C_D
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-4
4
8
12
16
20
24
α - °

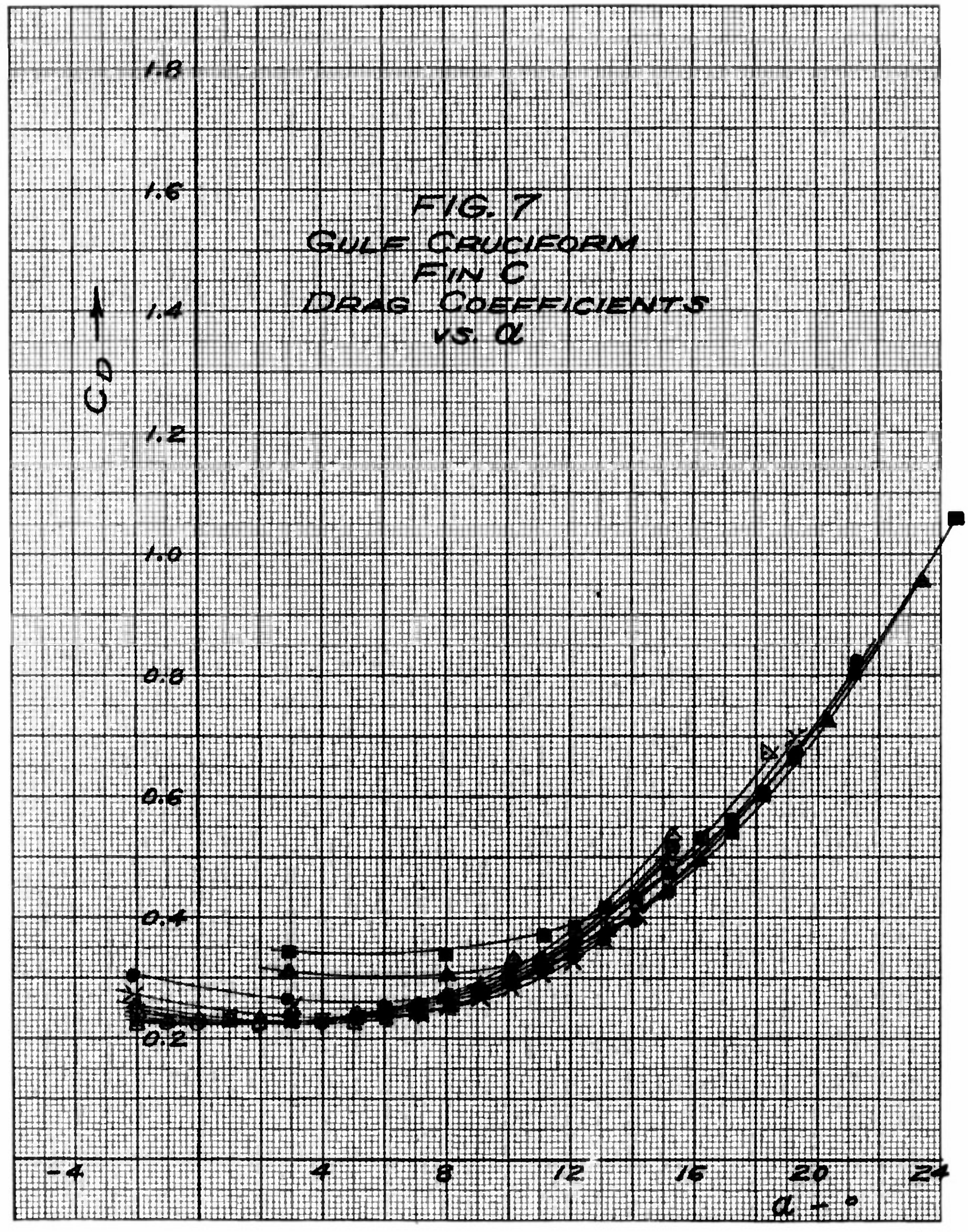


FIG. 7
GULF CRUCIFORM
FIN C
DRAG COEFFICIENTS
VS. α
C_D
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-4
4
8
12
16
20
24
α - °

44

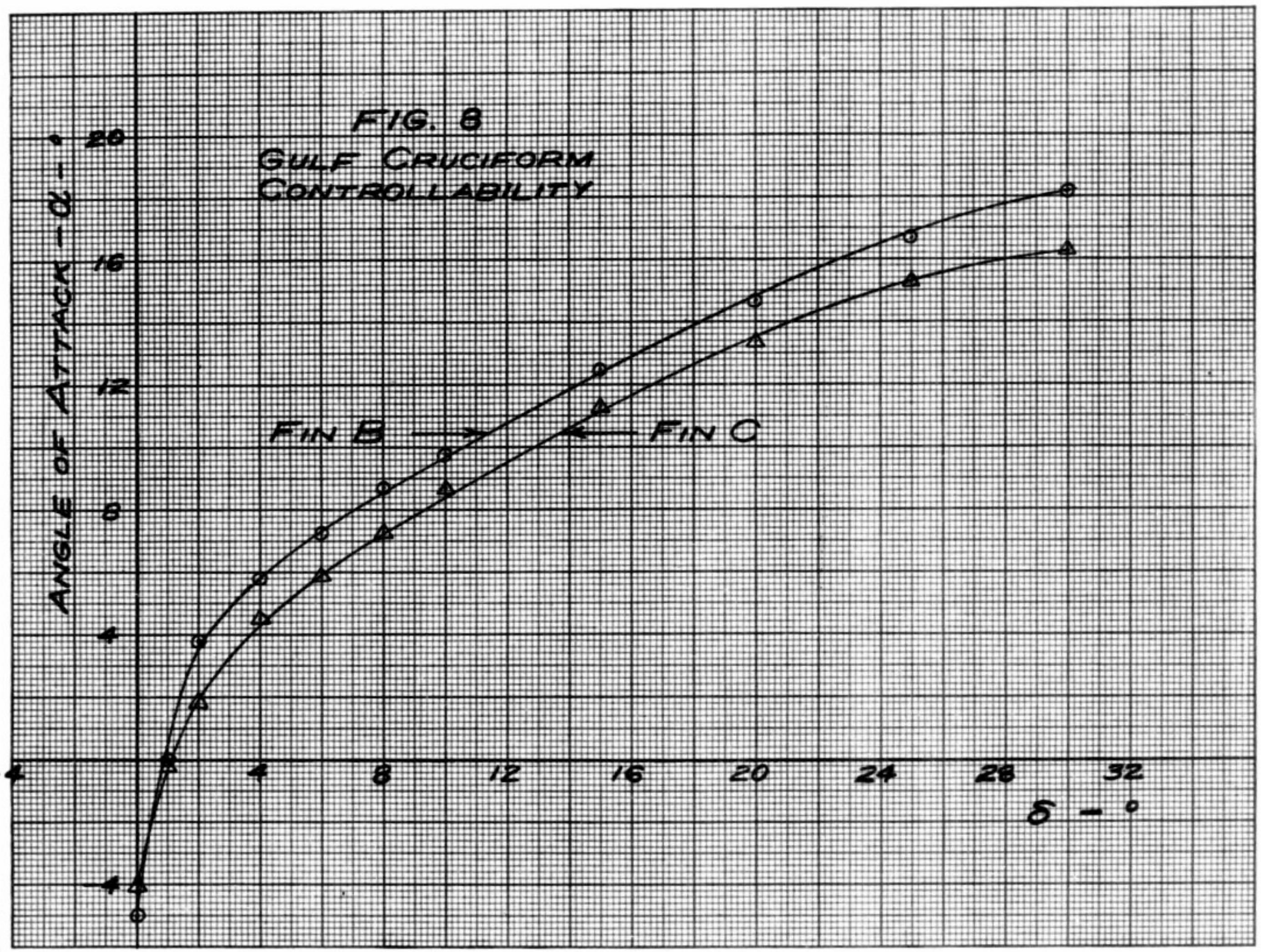


FIG. 8
GULF CRUCIFORM
CONTROLLABILITY
ANGLE OF ATTACK - α - °
FIN B
FIN C
δ - °
-4
4
8
12
16
20
24
28
32

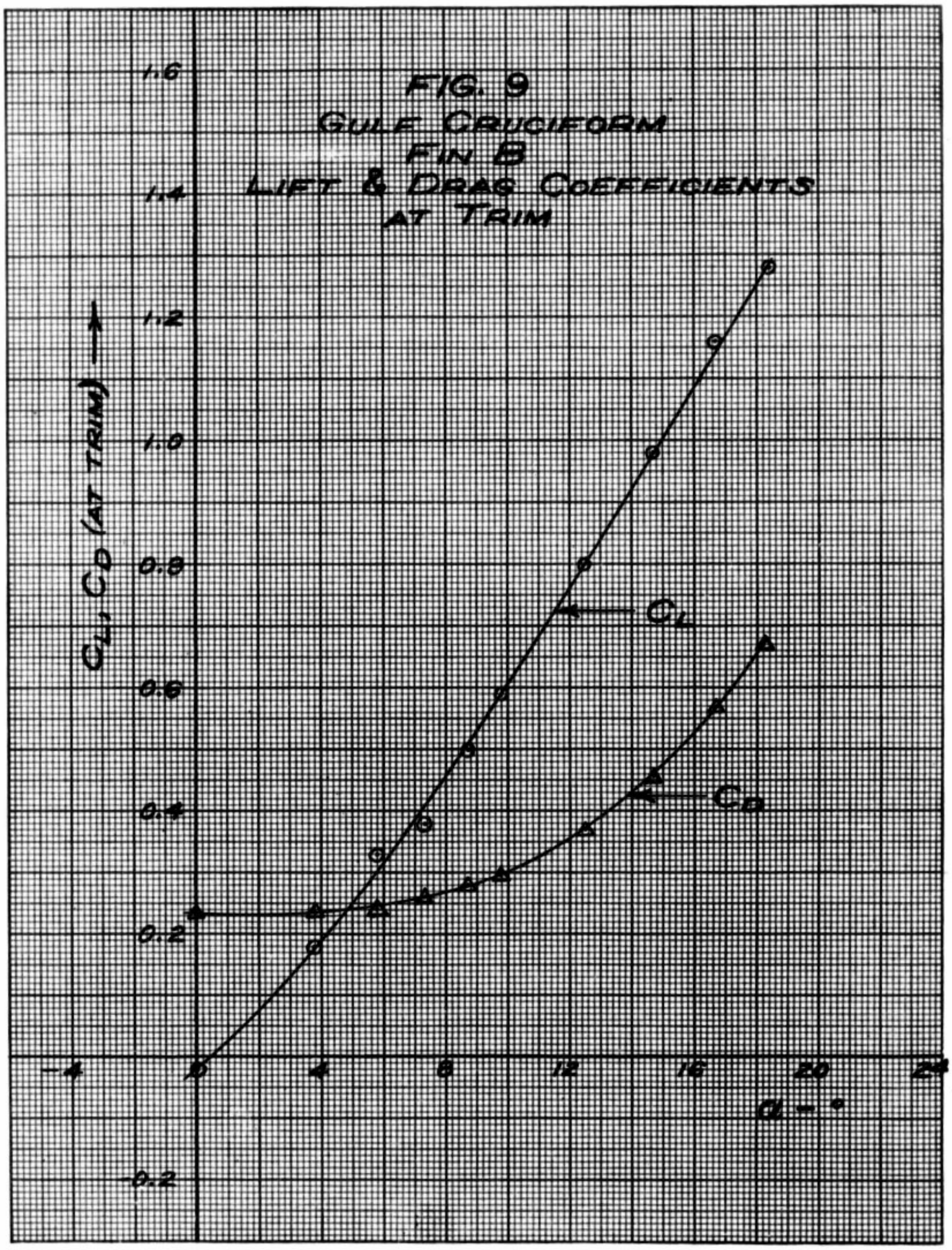


FIG. 9
GULF CRUCIFORM
FIN B
LIFT & DRAG COEFFICIENTS
AT TRIM
C_L, C_D (AT TRIM) →
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
-4
0
4
8
12
16
20
24
α - °
C_L
C_D

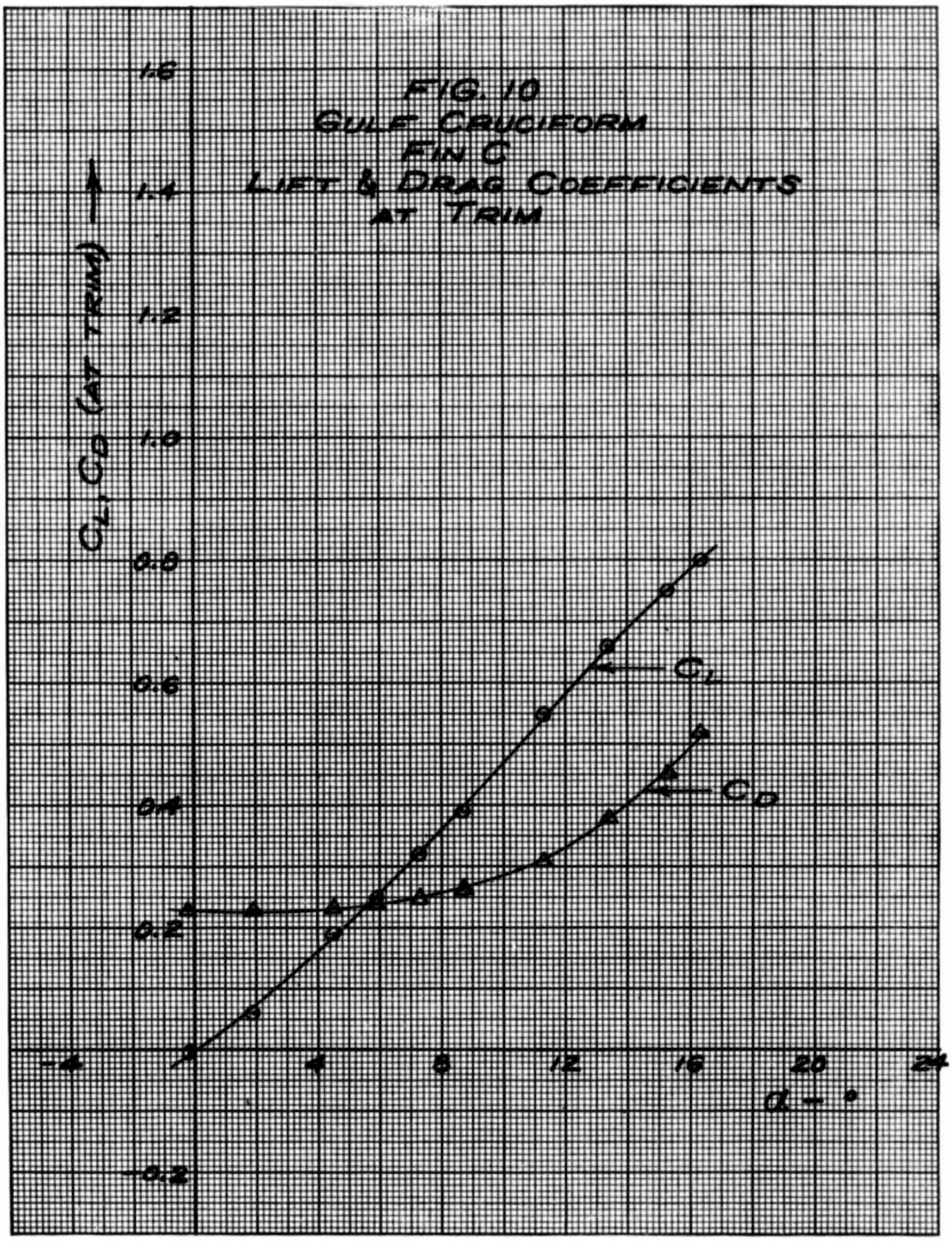


FIG. 10
GULF CRUCIFORM
FIN C
LIFT & DRAG COEFFICIENTS
AT TRIM
C_L, C_D (AT TRIM)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
-4
4
8
12
16
20
24
α – °
C_L
C_D

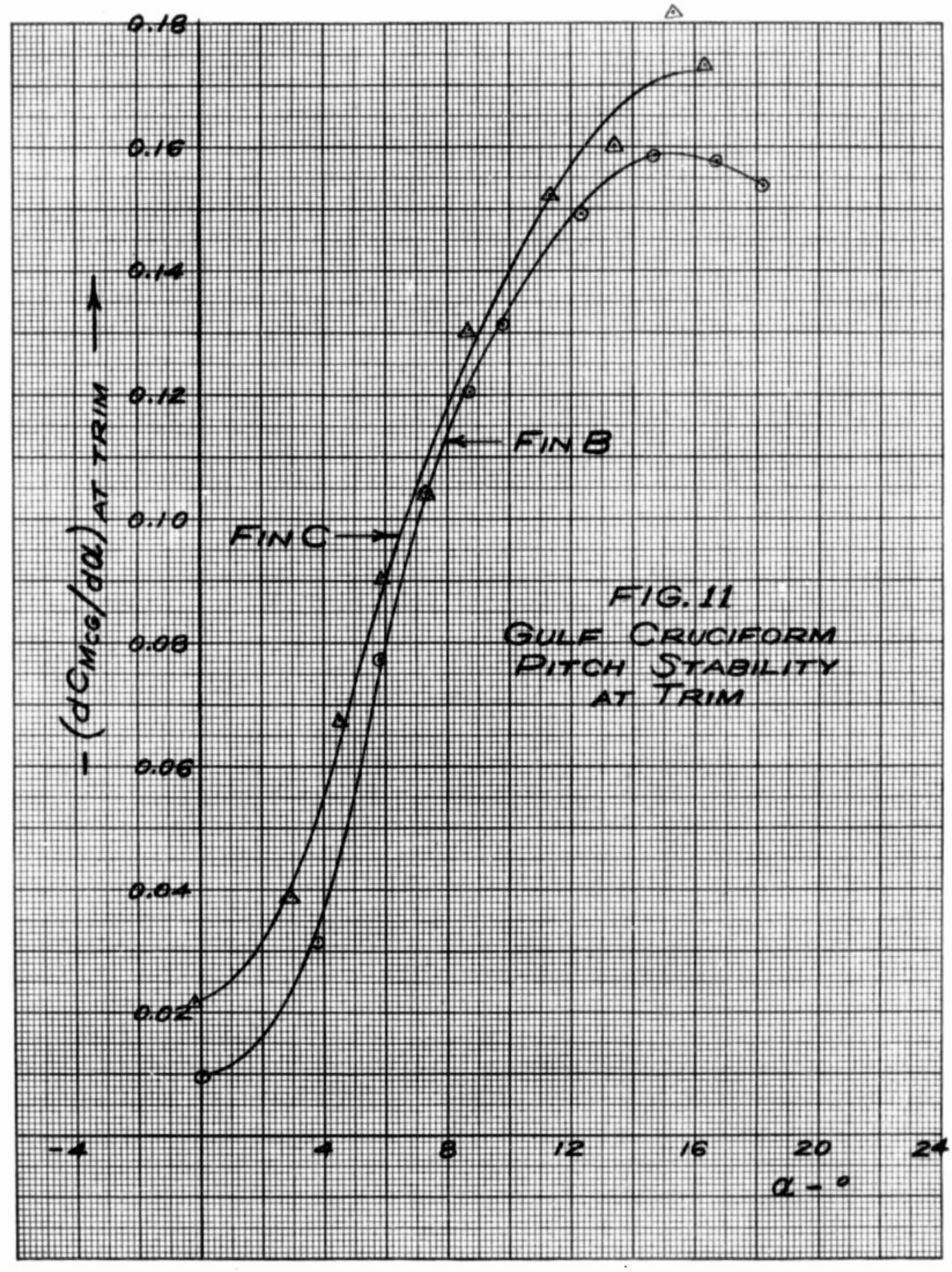


FIG. 11
GULF CRUCIFORM
PITCH STABILITY
AT TRIM

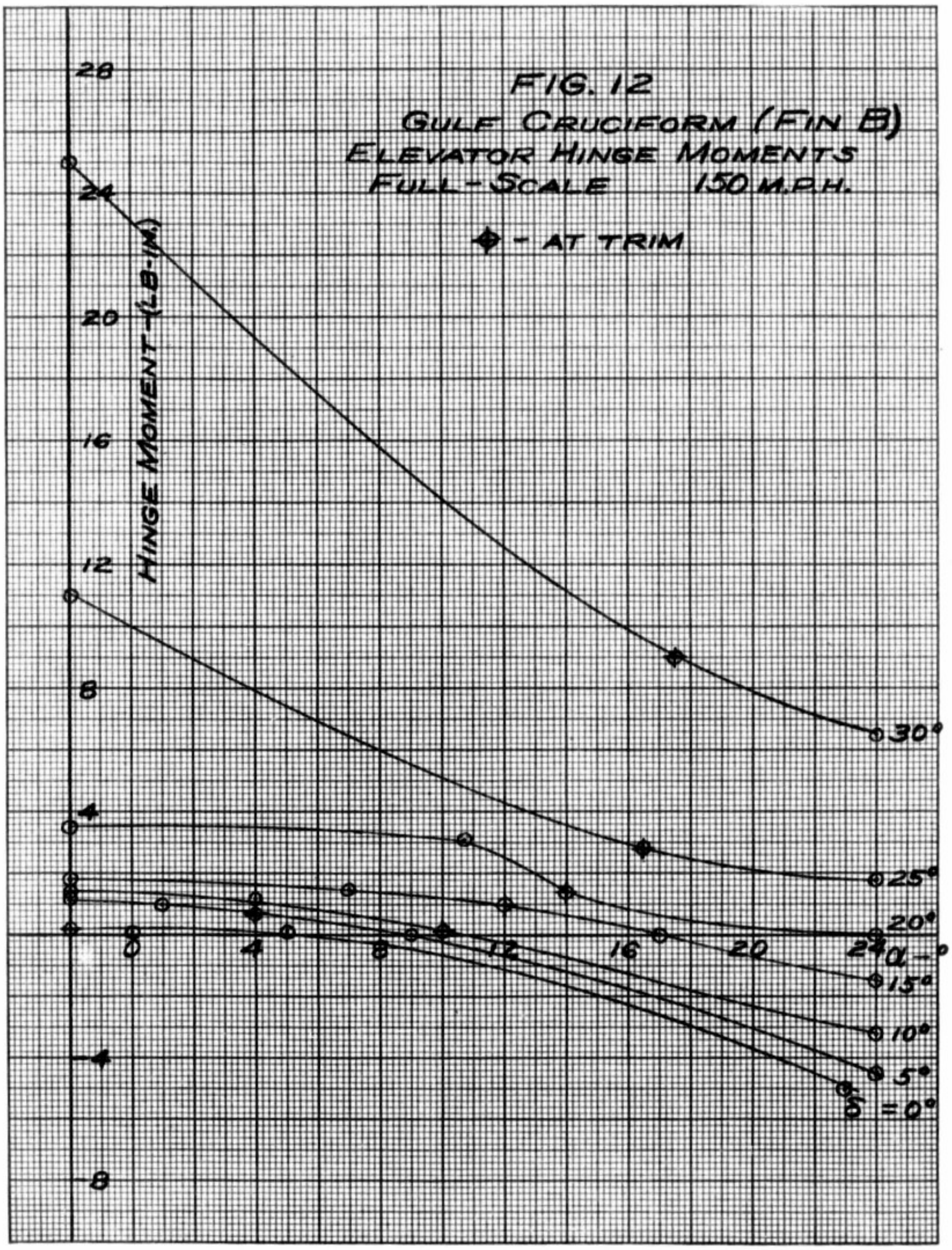


FIG. 12
GULF CRUCIFORM (FIN B)
ELEVATOR HINGE MOMENTS
FULL-SCALE 150 M.P.H.
- AT TRIM
HINGE MOMENT - (LB-IN.)
28
24
20
16
12
8
4
-4
-8
0
4
8
12
16
20
24
α - °
30°
25°
20°
15°
10°
5°
δ = 0°

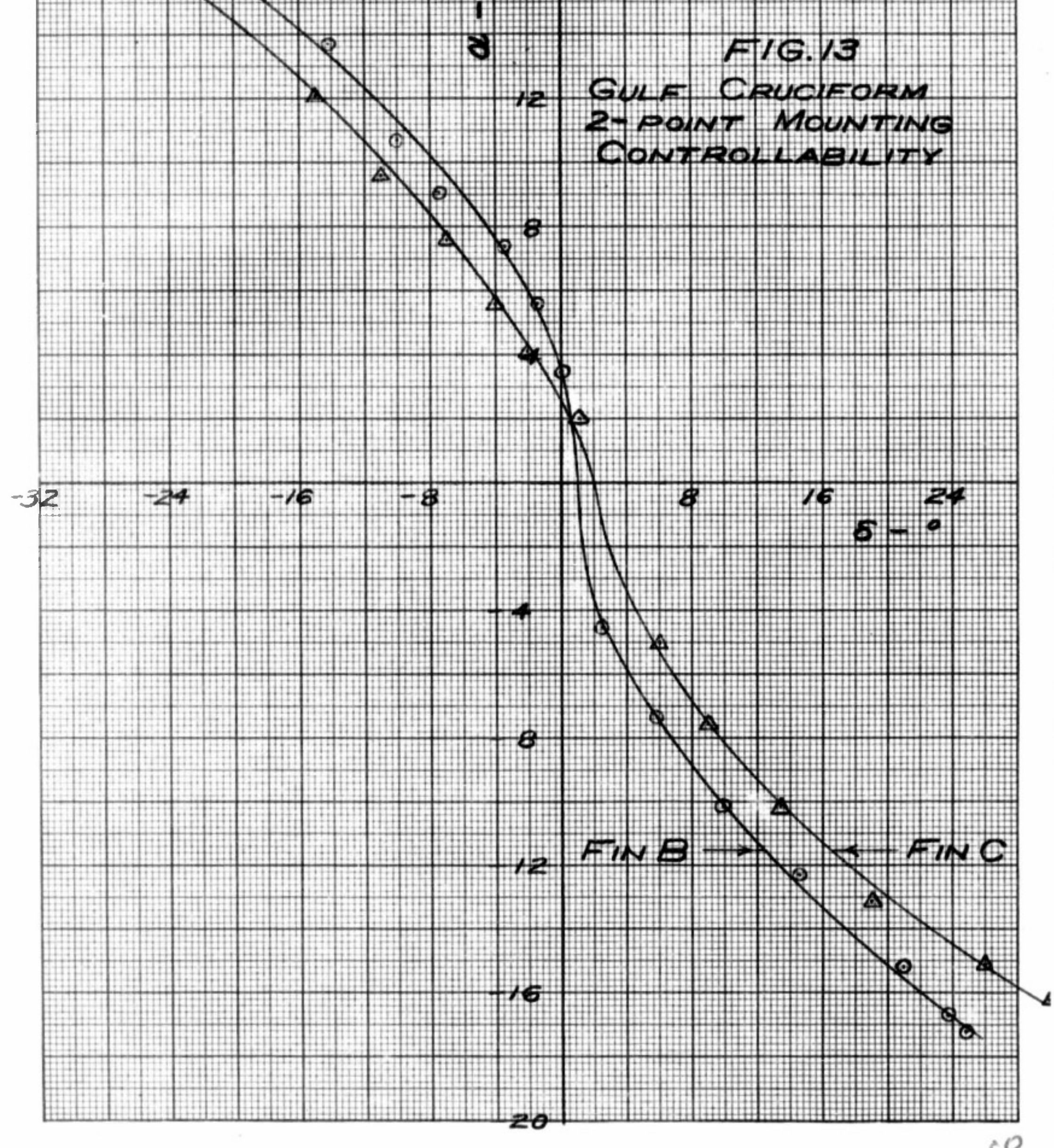


FIG. 13
GULF CRUCIFORM
2-POINT MOUNTING
CONTROLLABILITY
FIN B
FIN C
δ - °
20
16
12
8
4
-4
8
12
16
20
-32
-24
-16
-8
8
16
24

50

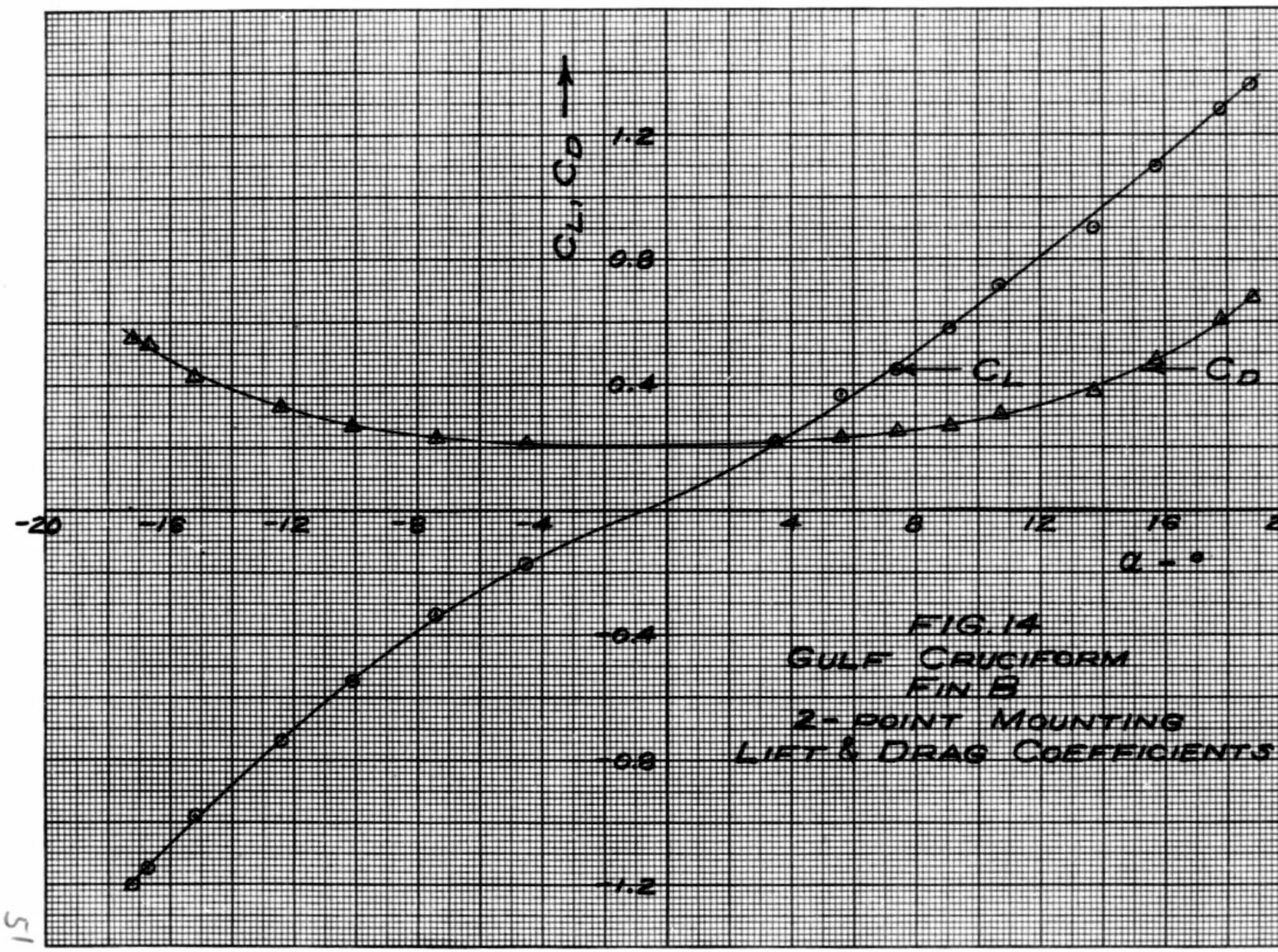


FIG. 14
GULF CRUCIFORM
FIN B
2-POINT MOUNTING
LIFT & DRAG COEFFICIENTS

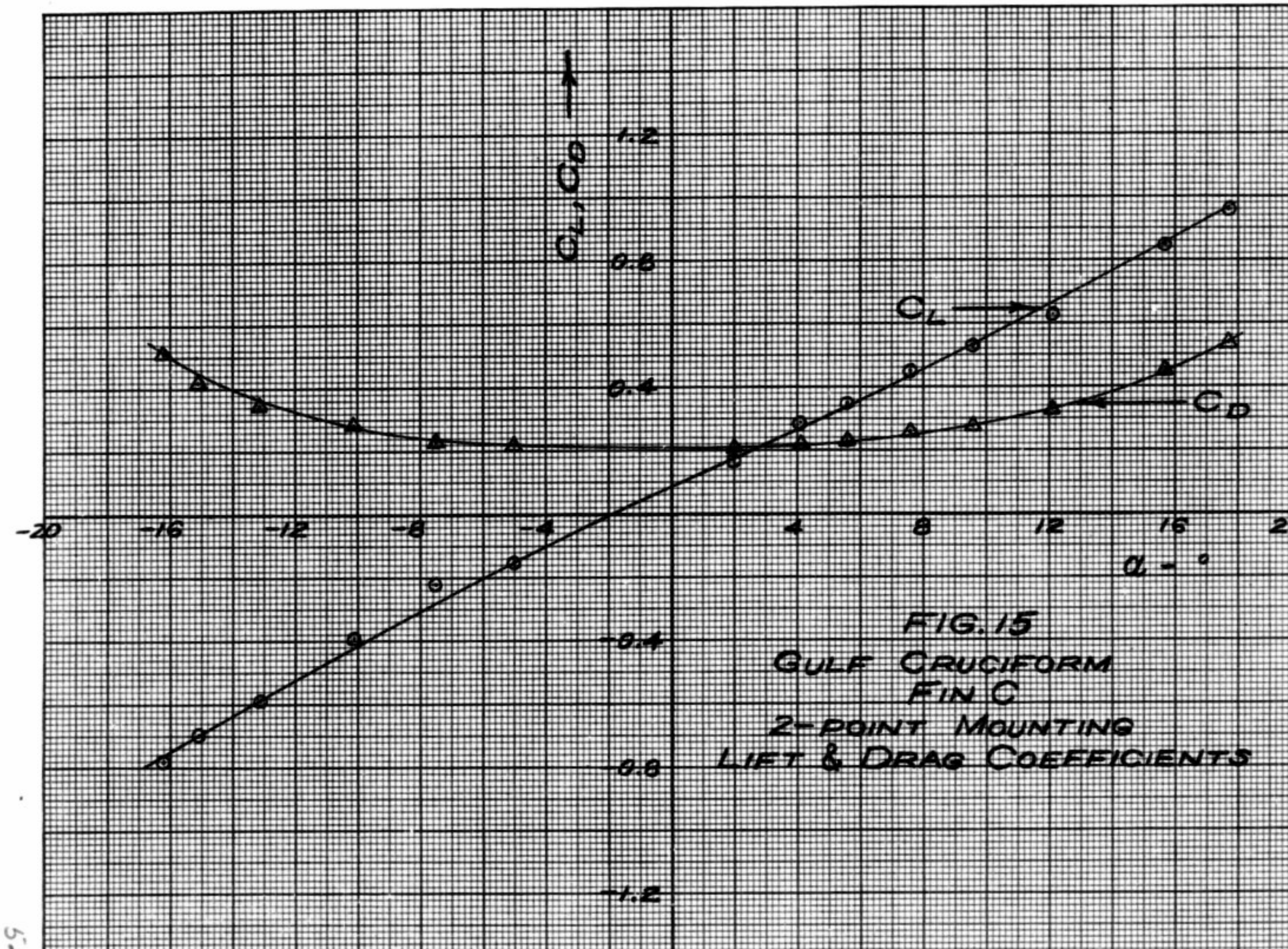


FIG. 15
GULF CRUCIFORM
FIN C
2-POINT MOUNTING
LIFT & DRAG COEFFICIENTS

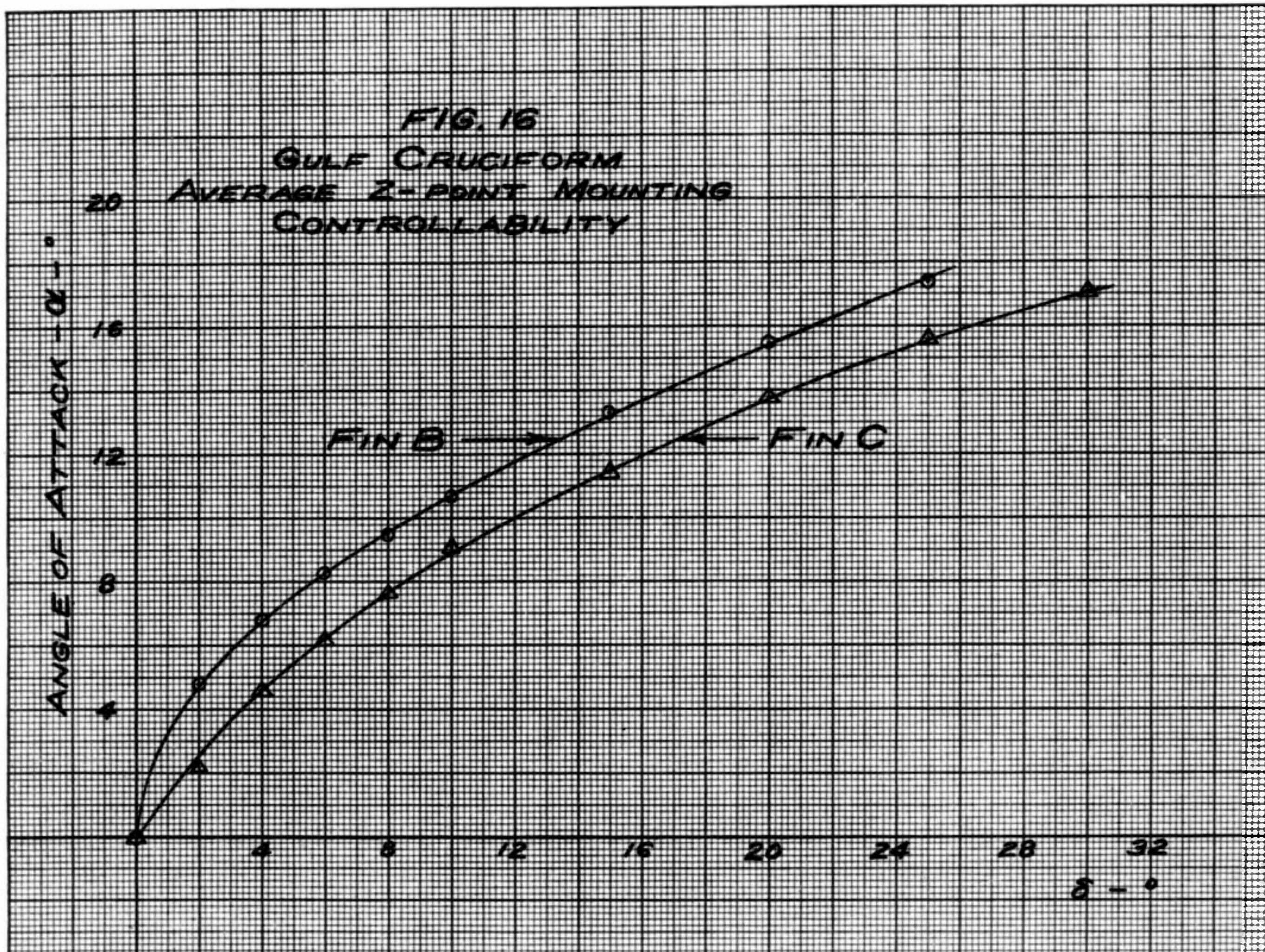


FIG. 16
GULF CRUCIFORM
AVERAGE Z-POINT MOUNTING
CONTROLLABILITY
FIN B
FIN C
ANGLE OF ATTACK - α - °
δ - °
4
8
12
16
20
24
28
32

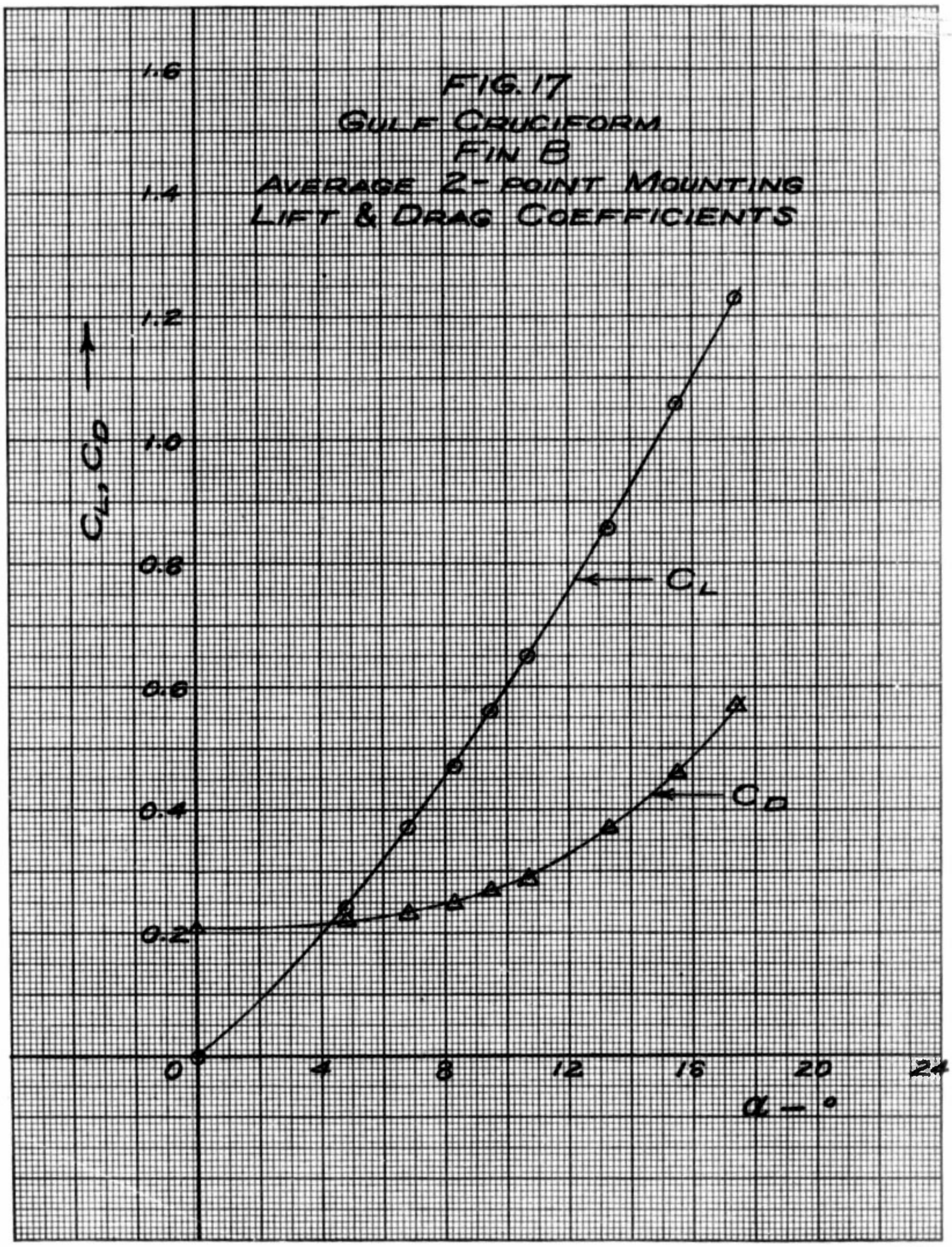


FIG. 17
GULF CRUCIFORM
FIN B
AVERAGE 2-POINT MOUNTING
LIFT & DRAG COEFFICIENTS
C_L, C_D
C_L
C_D
α — °
0
4
8
12
16
20
24
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

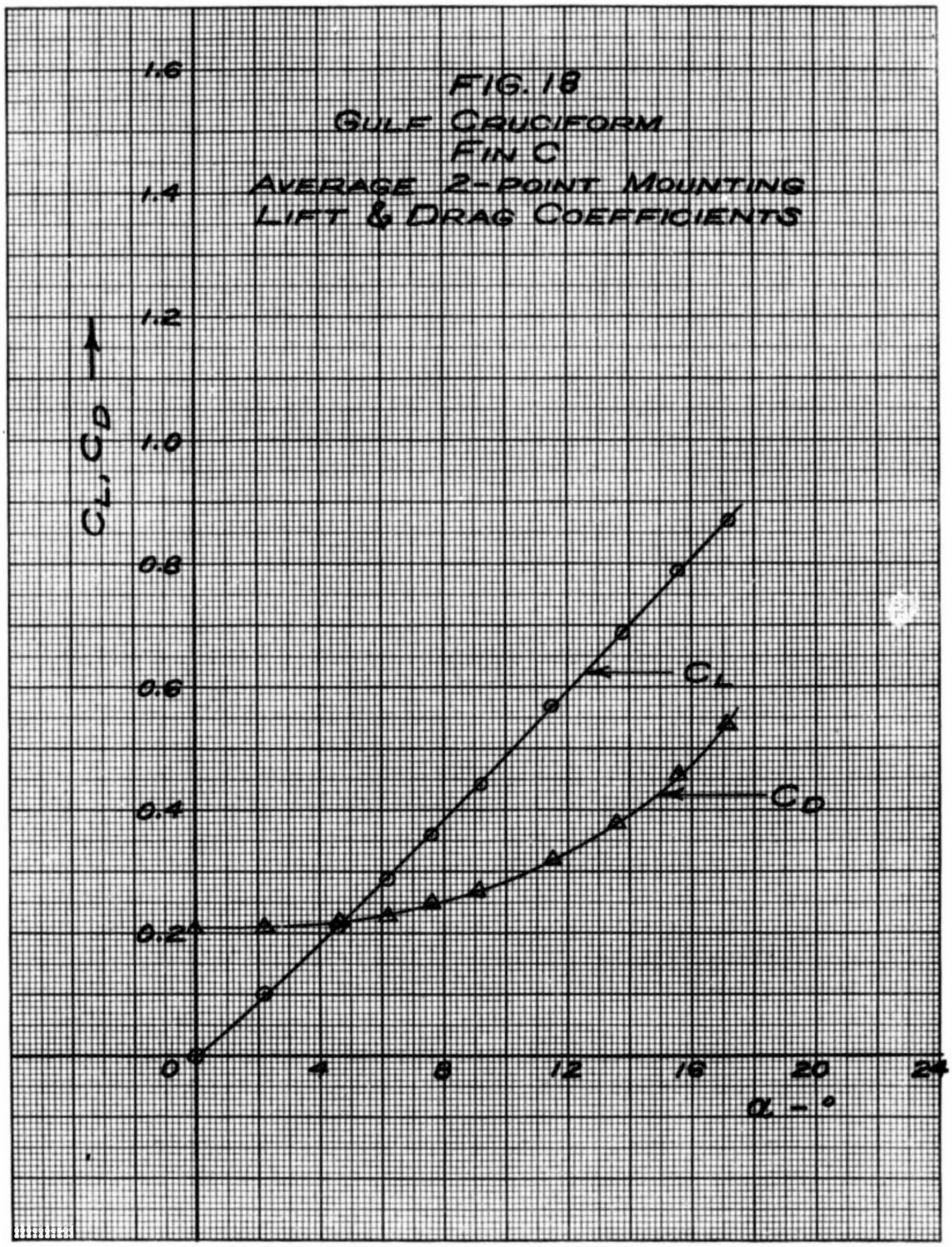


FIG. 18
GULF CRUCIFORM
FIN C
AVERAGE 2-POINT MOUNTING
LIFT & DRAG COEFFICIENTS
C_L, C_D
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
4
8
12
16
20
24
α - °
C_L
C_D

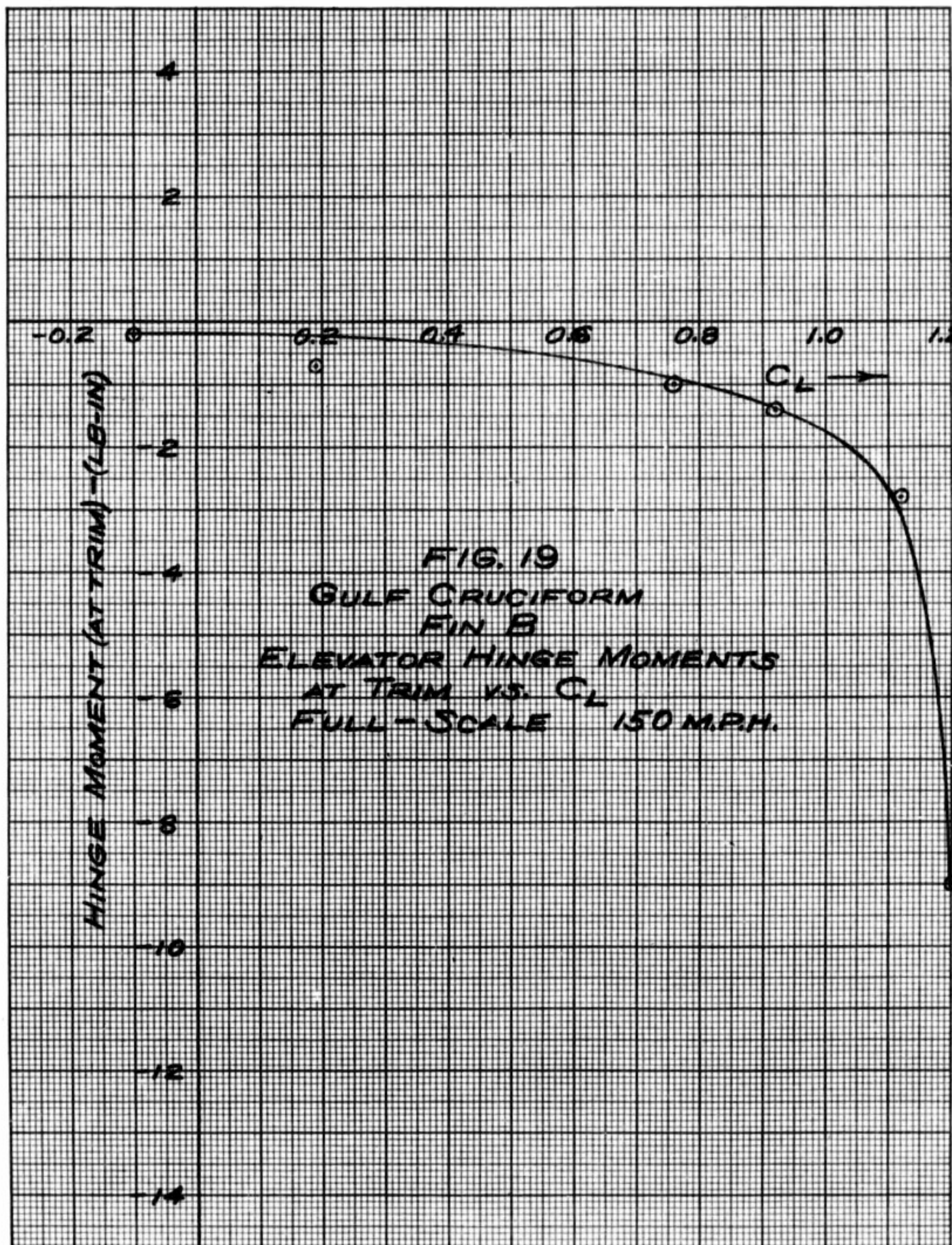


FIG. 19
GULF CRUCIFORM
FIN B
ELEVATOR HINGE MOMENTS
AT TRIM VS. C_L
FULL-SCALE 150 M.P.H.
HINGE MOMENT (AT TRIM) - (LB-IN)
C_L
-0.2
0.2
0.4
0.6
0.8
1.0
1.2
4
2
-2
-4
-6
-8
-10
-12
-14

APPENDIX II. B. ROLL TORQUE TESTS: FIGS. 20 - 28.

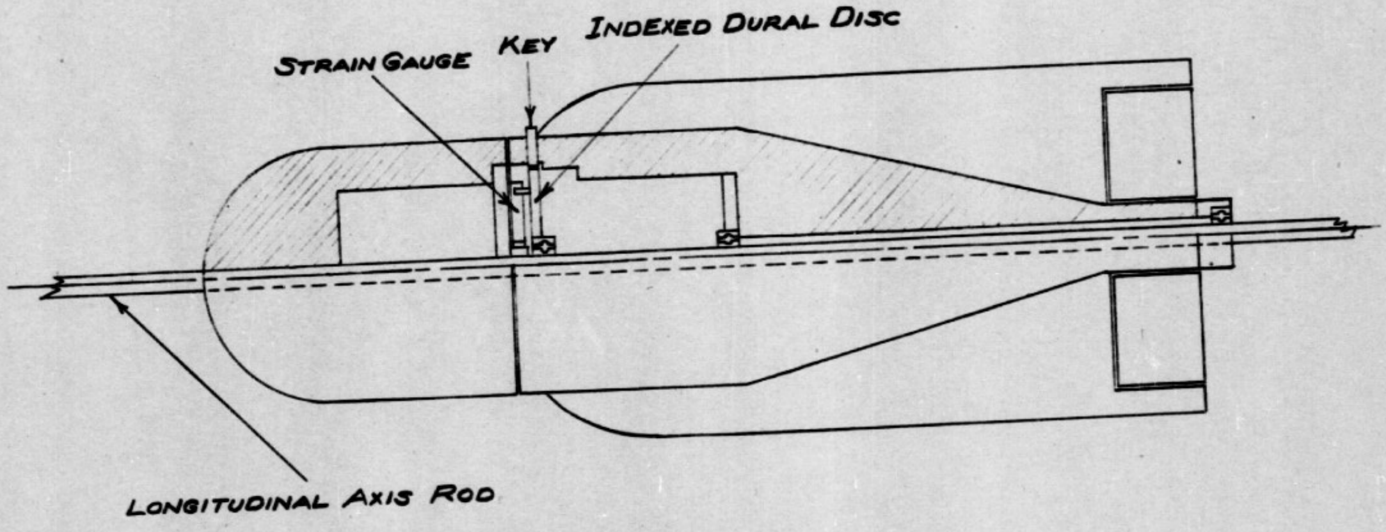


FIG. 20
ROLL TORQUE MODEL

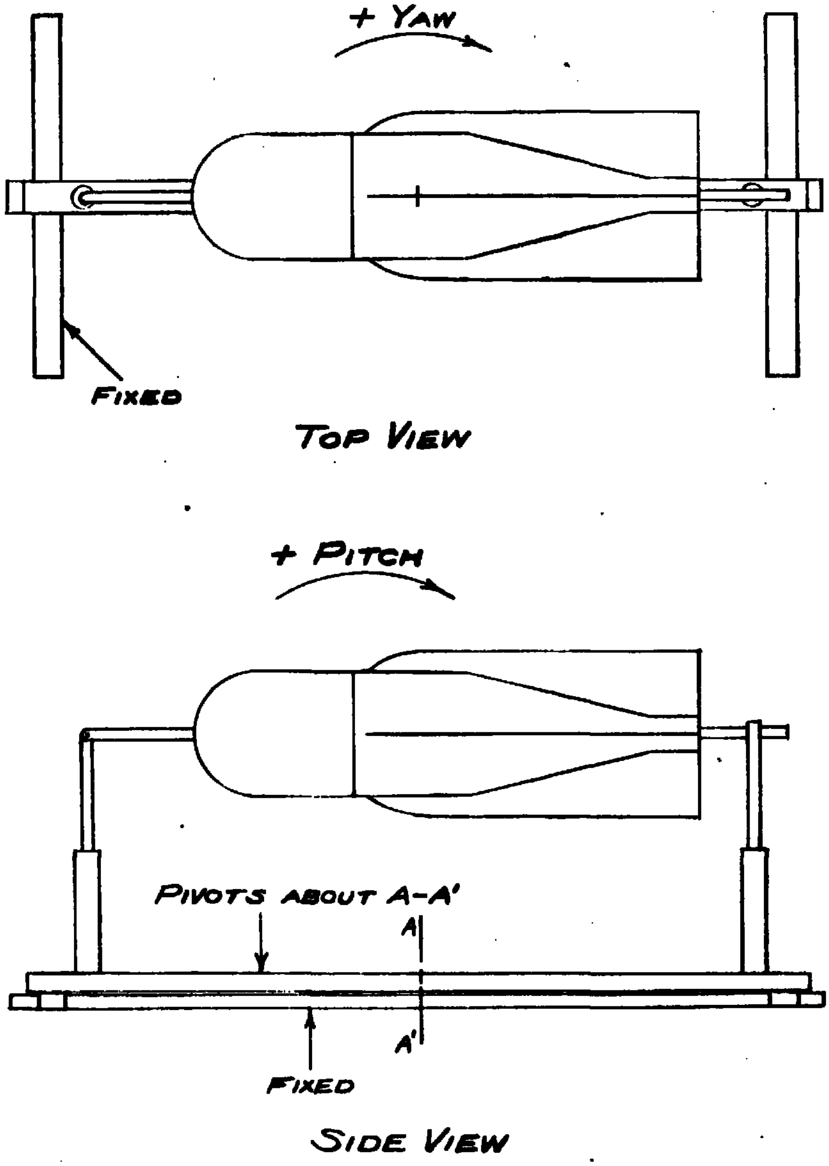


FIG. 21
ROLL TORQUE MODEL
TUNNEL MOUNTING

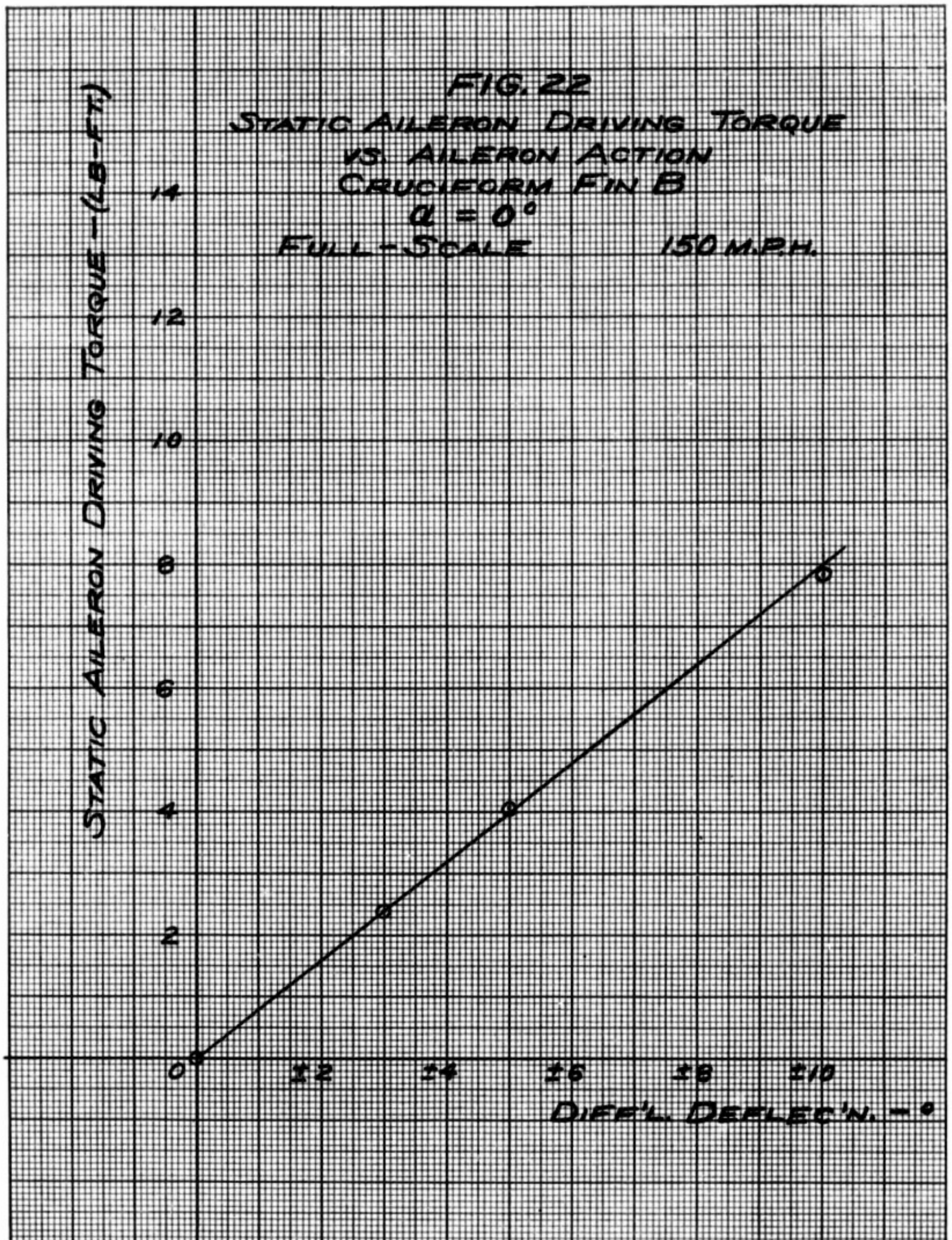


FIG. 22
STATIC AILERON DRIVING TORQUE
VS. AILERON ACTION
CRUCIFORM FIN B
$\alpha = 0°$
FULL-SCALE 150 M.P.H.
STATIC AILERON DRIVING TORQUE — (LB-FT.)
14
12
10
8
6
4
2
0
±2
±4
±6
±8
±10
DIFF'L. DEFLEC'N. — °

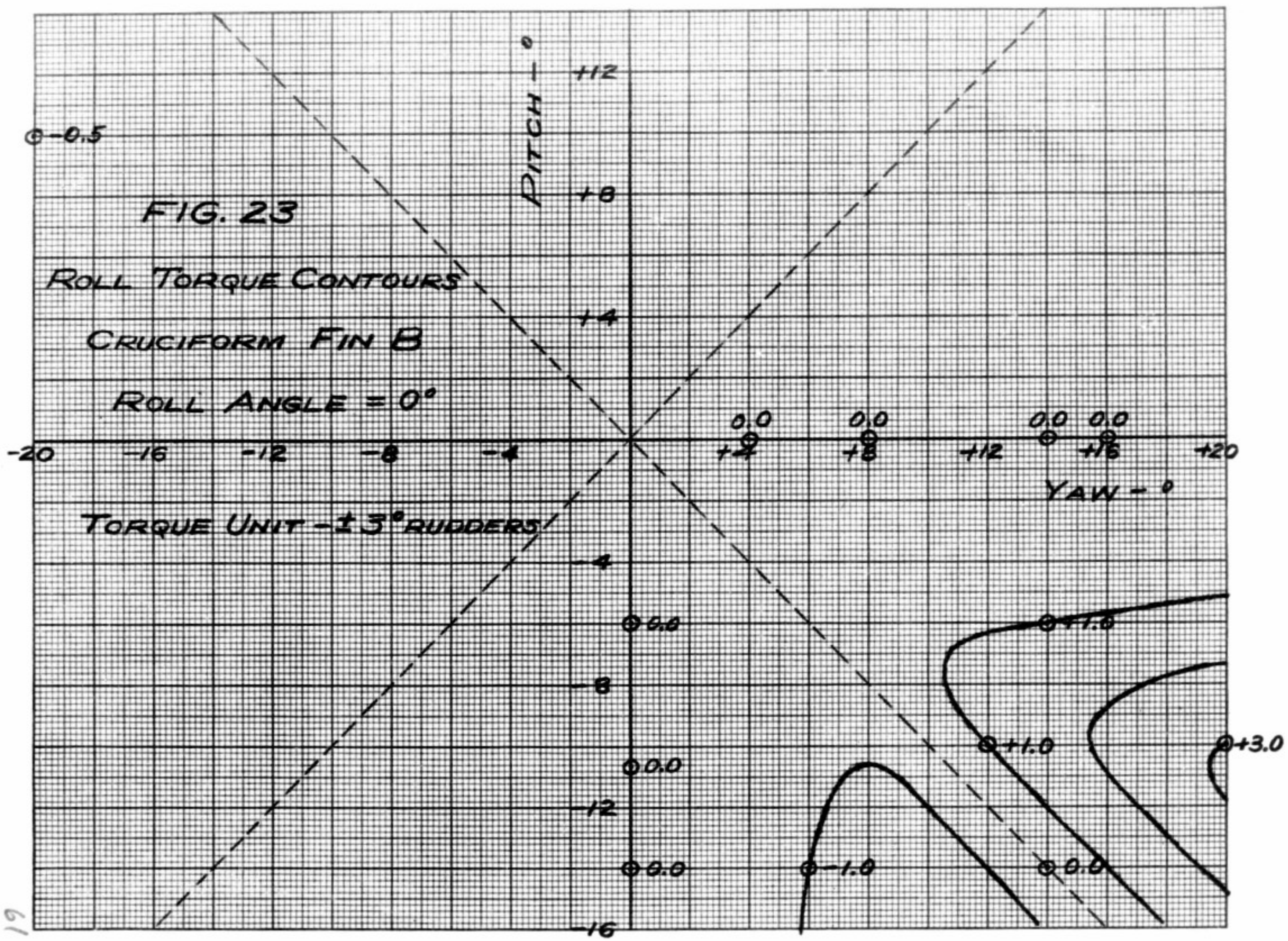


FIG. 23

ROLL TORQUE CONTOURS

CRUCIFORM FIN B

ROLL ANGLE = 0°

TORQUE UNIT – ±3° RUDDERS

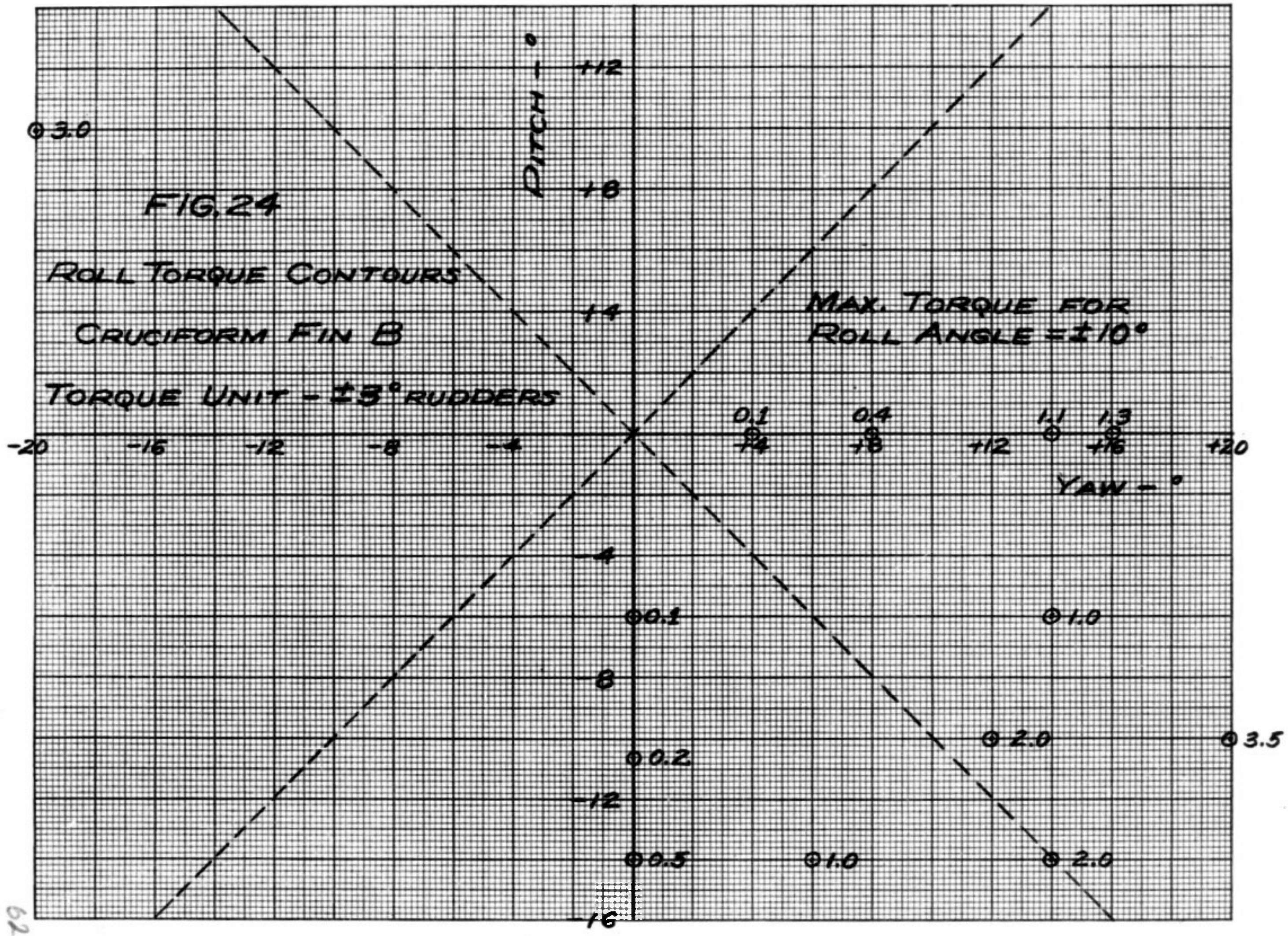


FIG. 24
ROLL TORQUE CONTOURS
CRUCIFORM FIN B
TORQUE UNIT - ±3° RUDDERS
MAX. TORQUE FOR
ROLL ANGLE = ±10°
PITCH - °
YAW - °
-20
-16
-12
-8
-4
+4
+8
+12
+16
+20
0.1
0.4
1.1
1.3
3.0
1.0
2.0
3.5
0.2
0.5
1.0
2.0

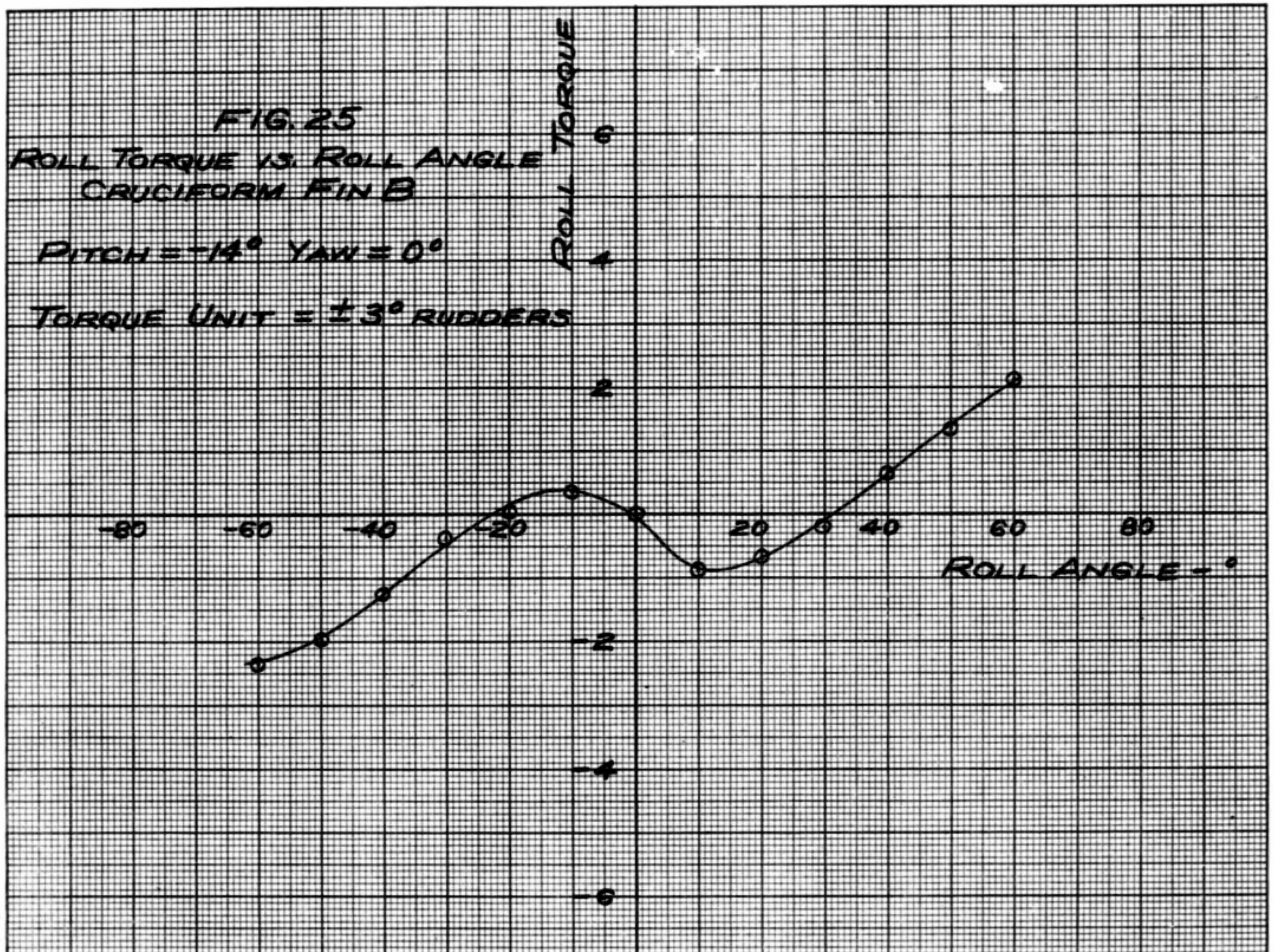


FIG. 25
ROLL TORQUE VS. ROLL ANGLE
CRUCIFORM FIN B
PITCH = -14° YAW = 0°
TORQUE UNIT = ± 3° RUDDERS
ROLL TORQUE
6
4
2
-2
-4
-6
-80
-60
-40
-20
20
40
60
80
ROLL ANGLE - °

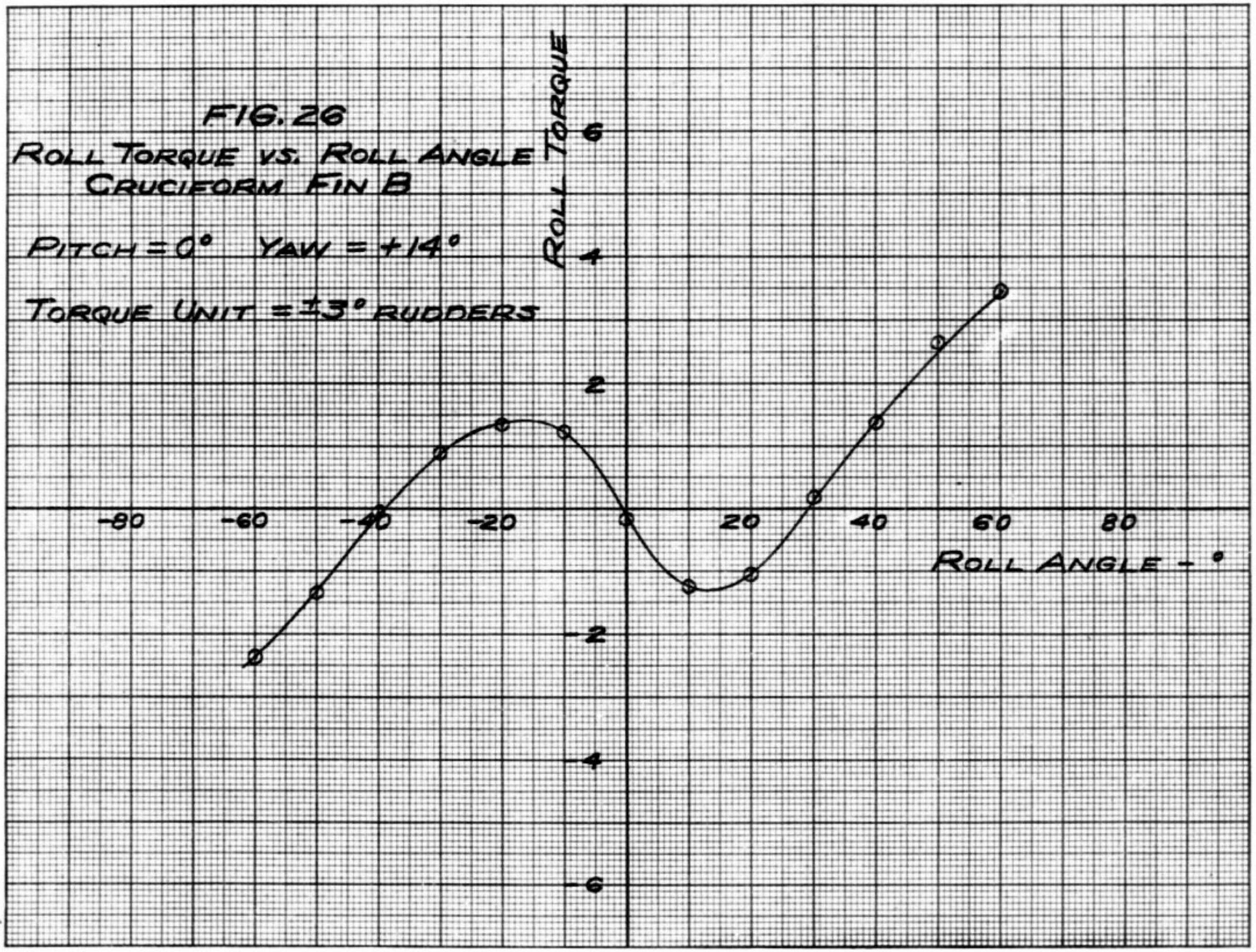
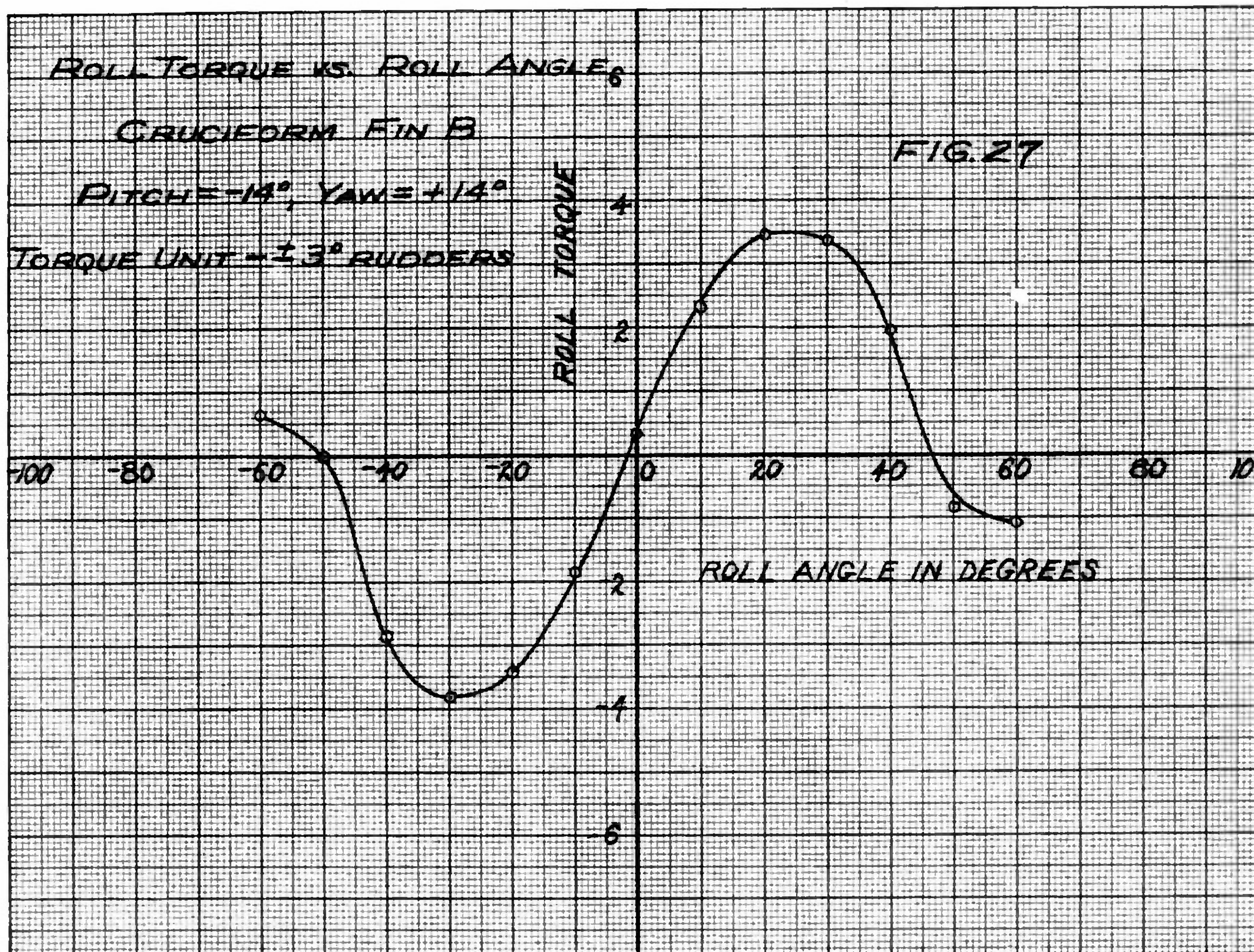


FIG. 26
ROLL TORQUE VS. ROLL ANGLE
CRUCIFORM FIN B
PITCH = 0°   YAW = +14°
TORQUE UNIT = ±3° RUDDERS
ROLL TORQUE
6
4
2
-2
-4
-6
-80
-60
-40
-20
20
40
60
80
ROLL ANGLE - °


ROLL TORQUE VS. ROLL ANGLE
CRUCIFORM FIN B
PITCH = -14°, YAW = +14°
TORQUE UNIT = ±3° RUDDERS
FIG. 27
ROLL TORQUE
ROLL ANGLE IN DEGREES
-100
-80
-60
-40
-20
0
20
40
60
80
100
6
4
2
-2
-4
-6

61

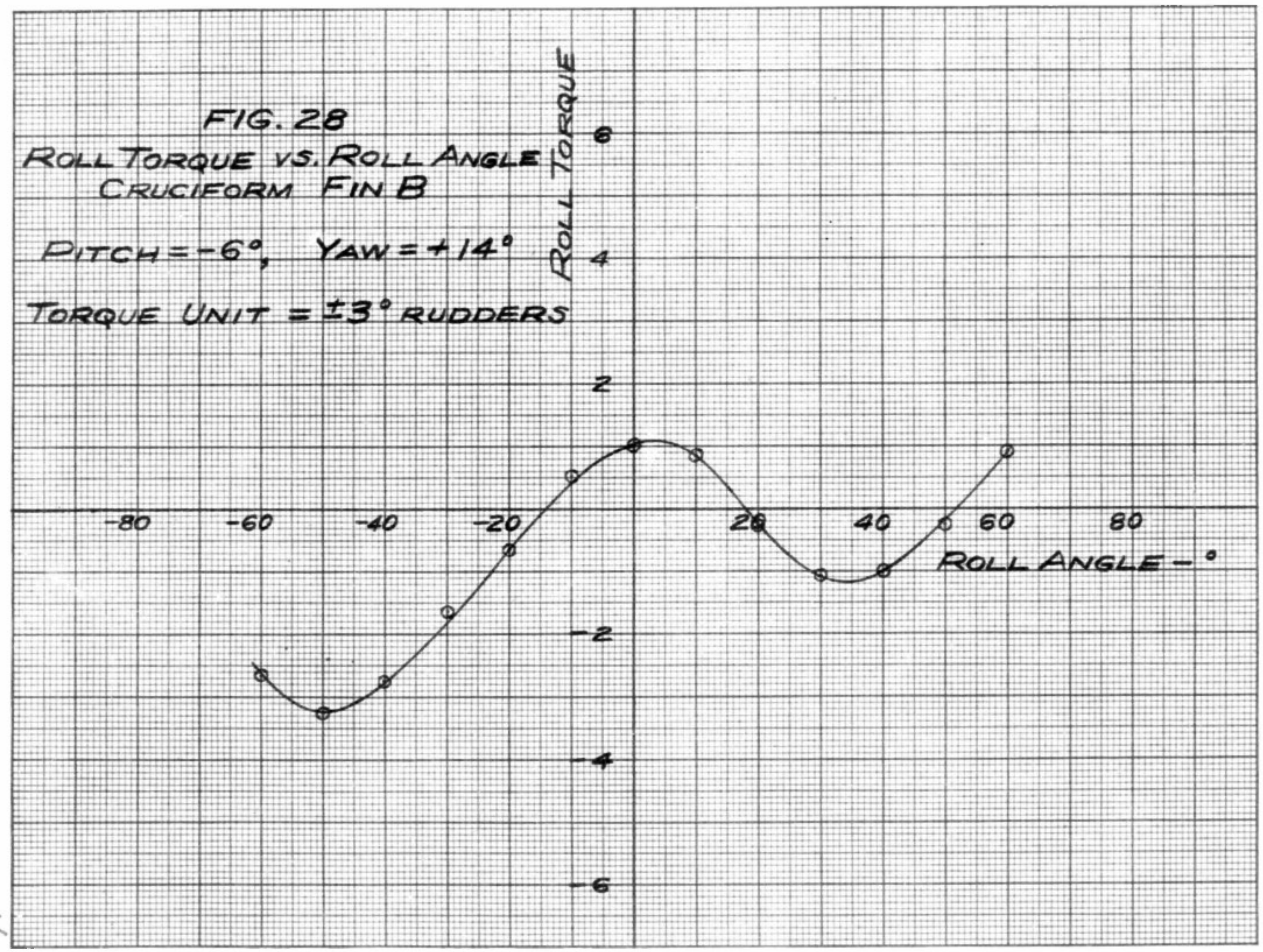


FIG. 28
ROLL TORQUE VS. ROLL ANGLE
CRUCIFORM FIN B
PITCH = -6°, YAW = +14°
TORQUE UNIT = ±3° RUDDERS
ROLL TORQUE
6
4
2
-2
-4
-6
-80
-60
-40
-20
20
40
60
80
ROLL ANGLE - °

APPENDIX II. C. 1. FINAL SHROUD MODEL: FIGS. 29 - 40.

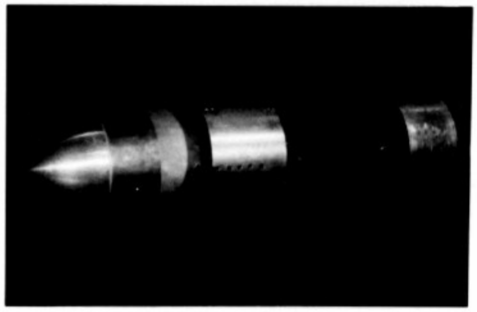


FIG. 29: DIRIGIBLE SHROUDED BOMB

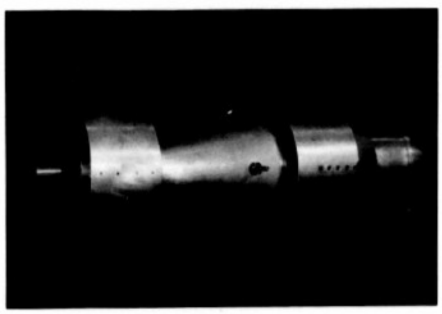


FIG. 30: DIRIGIBLE SHROUDED BOMB

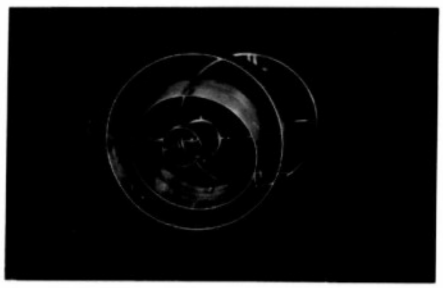


FIG. 31: DIRIGIBLE SHROUDED BOMB
with ROTATED CONTROL SHROUD

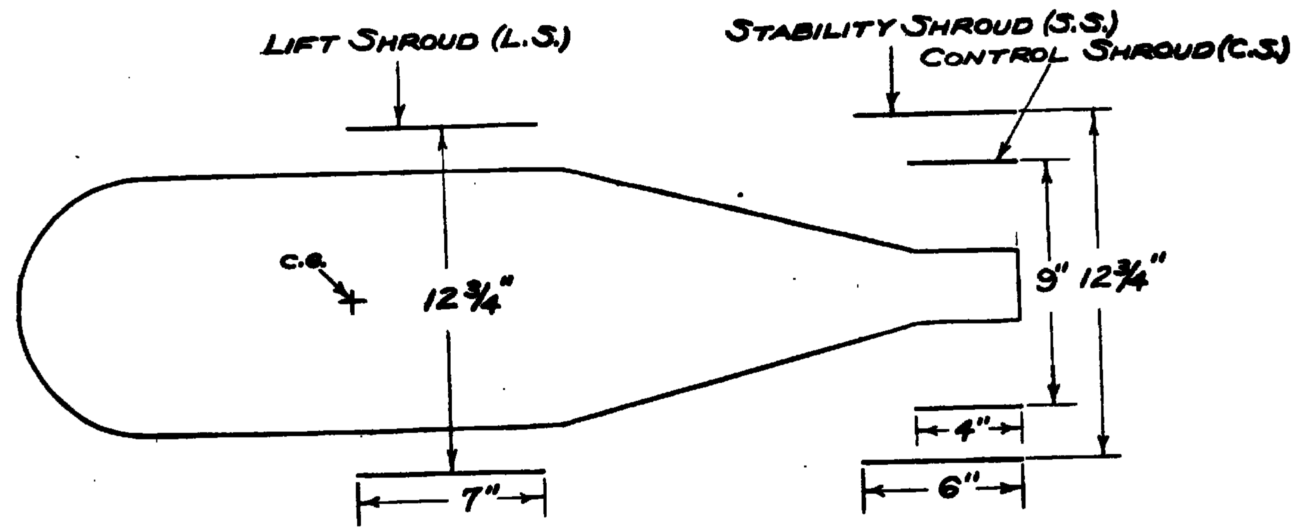


FIG. 32
FINAL SHROUD MODEL

SCALE OF MODEL : 1/2
SHROUD THICKNESS : 1/8"

SHROUD MODEL SYMBOLS

SYMBOL	$\delta_{c.s.}$ (°)
⊹	-2
⊙	0
◬	+2
⊡	+4
⛛	+6
▷	+8
◿	+10
●	+15
▲	+20
■	+24

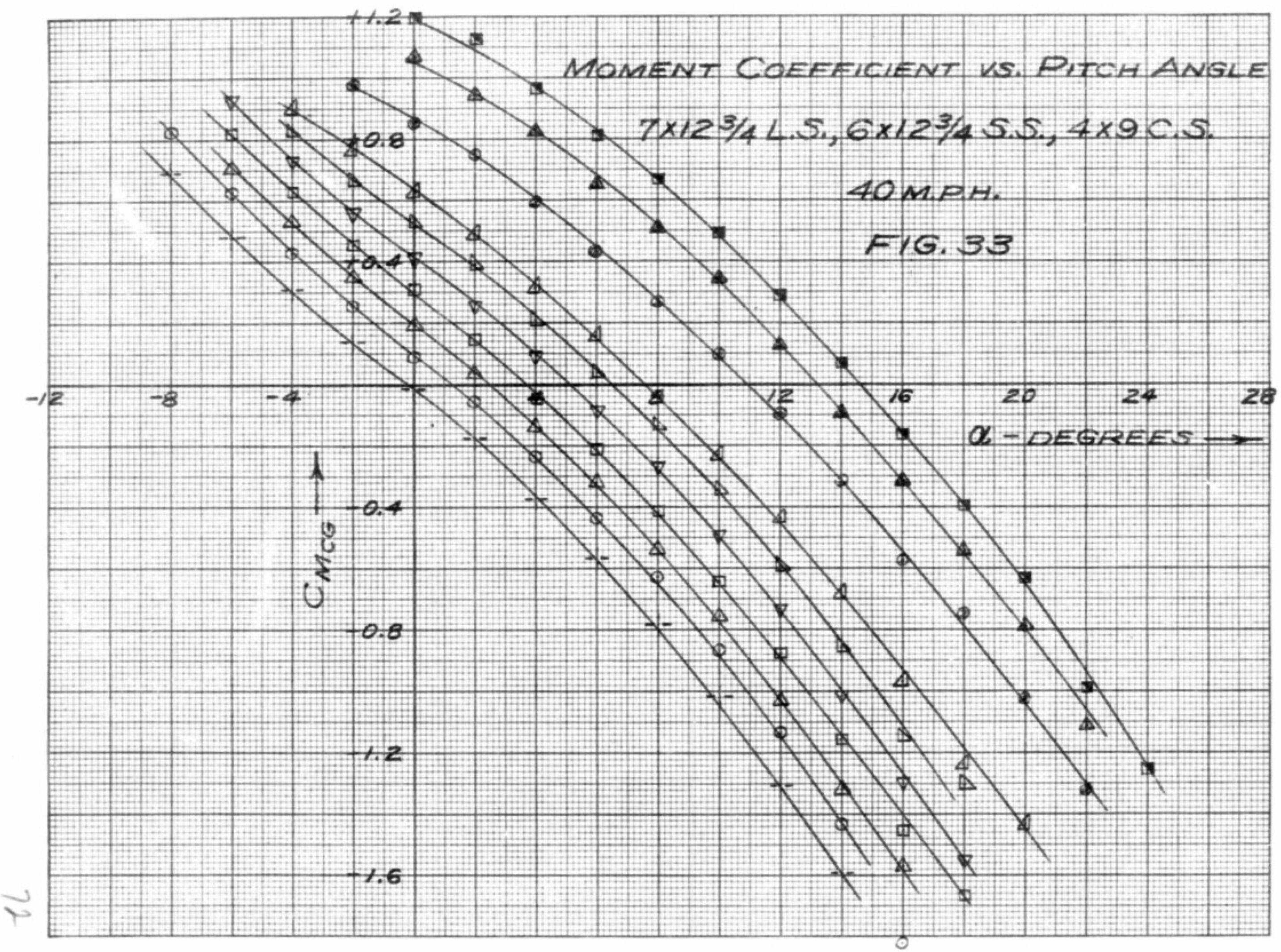
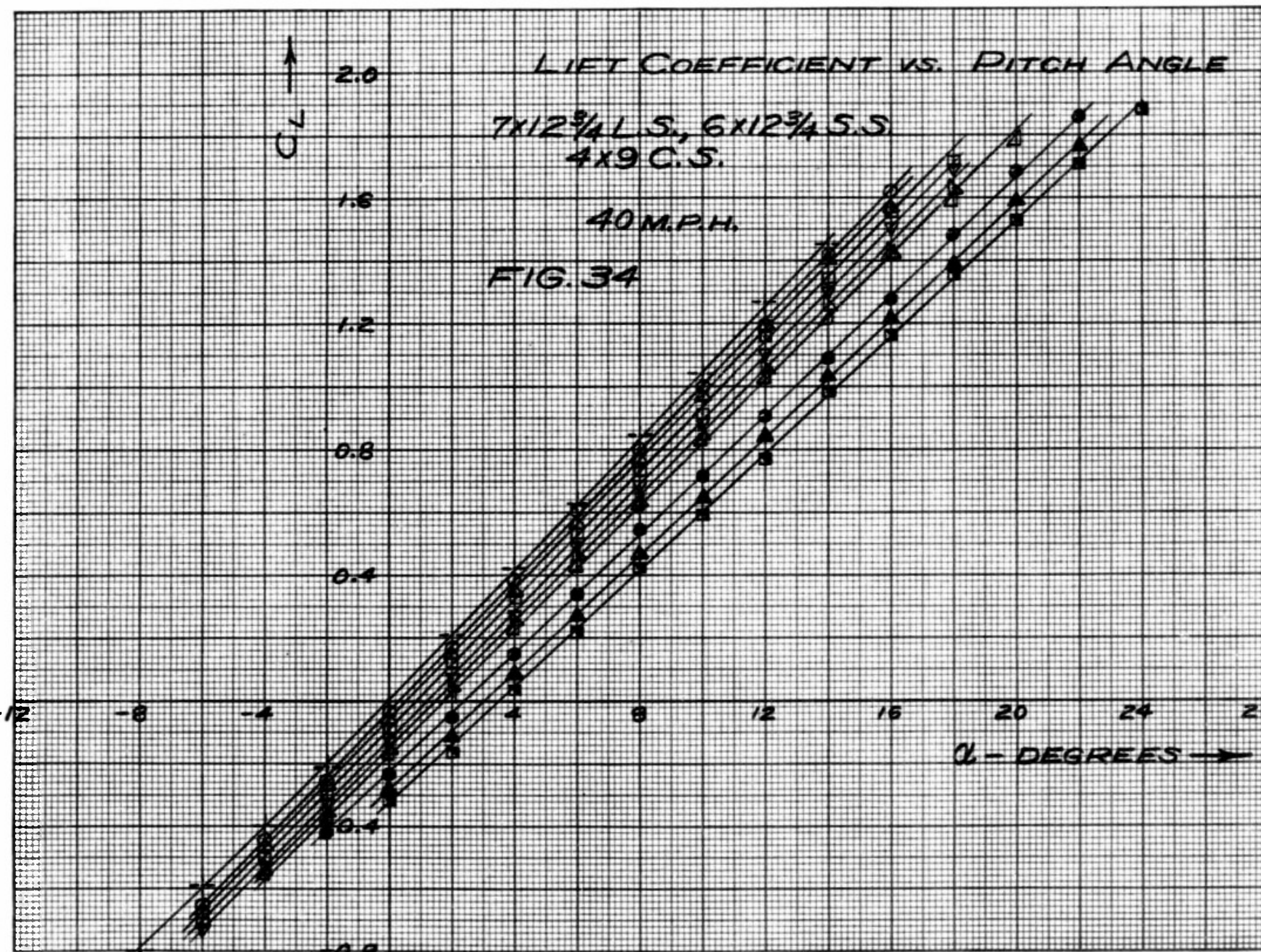
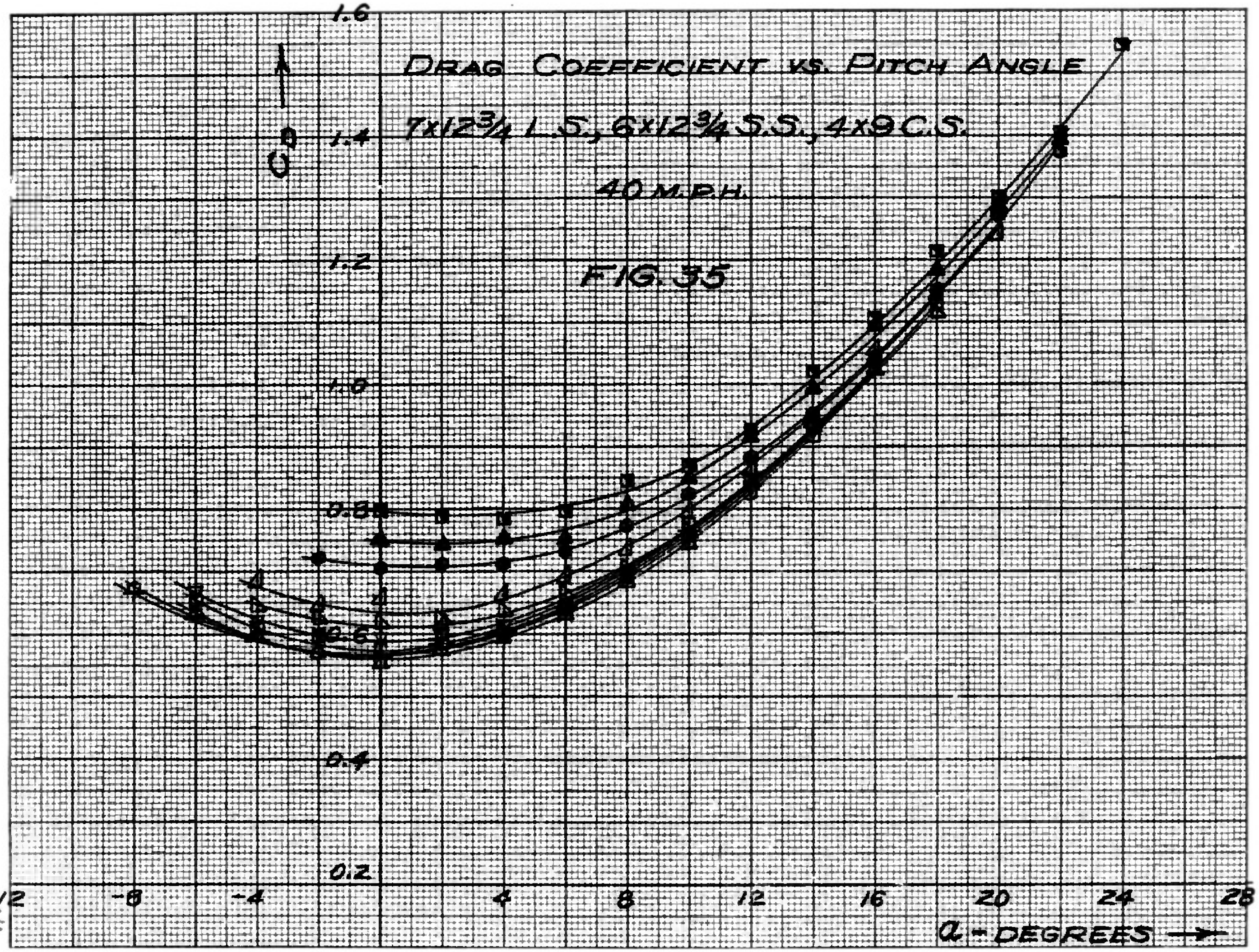
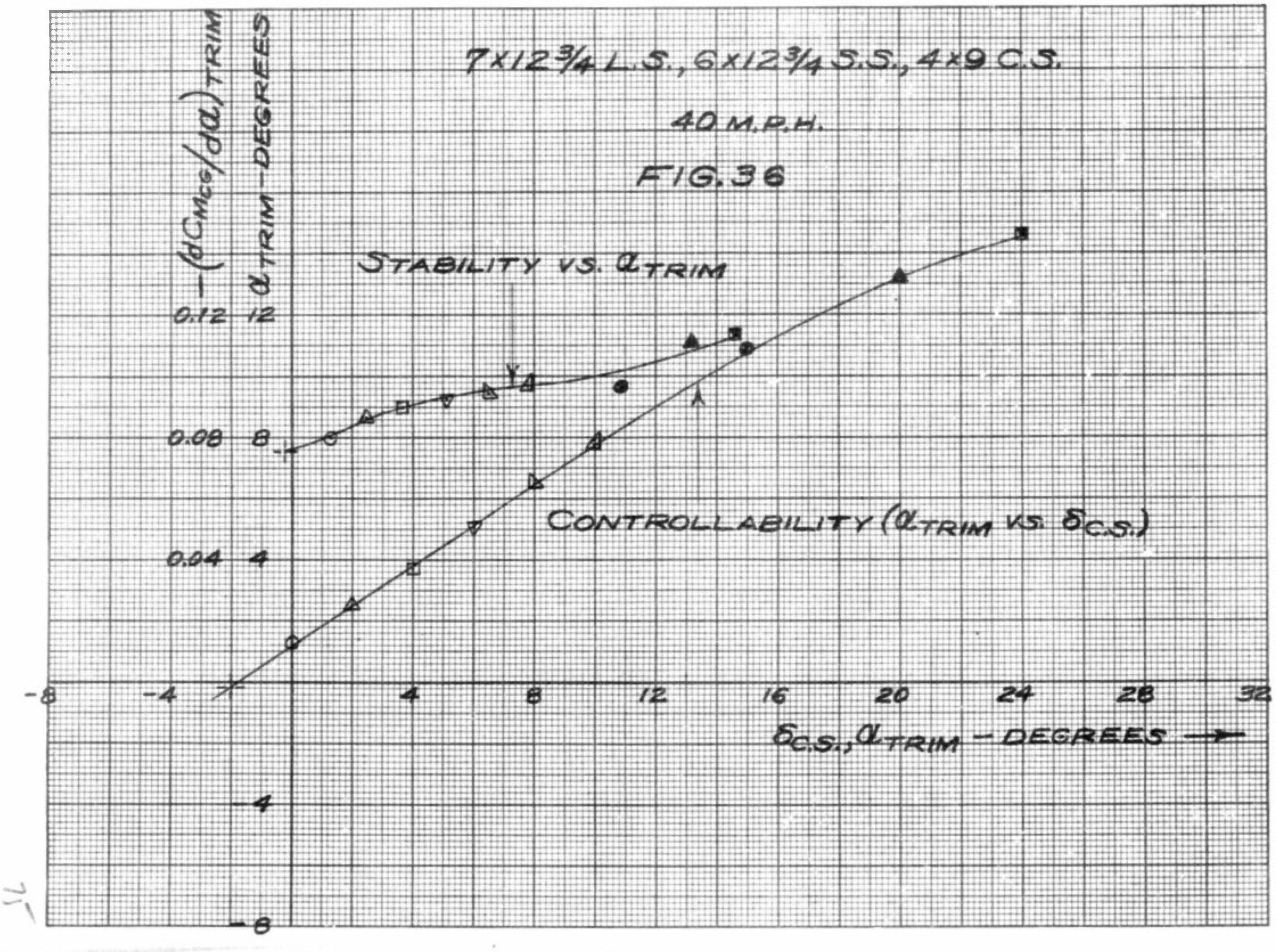

MOMENT COEFFICIENT VS. PITCH ANGLE
7X12¾ L.S., 6X12¾ S.S., 4X9 C.S.
40 M.P.H.
+1.2
+0.8
+0.4
-0.4
-0.8
-1.2
-1.6
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES →
$C_{M_{CG}}$ →

FIG. 33


LIFT COEFFICIENT VS. PITCH ANGLE
7x12¾ L.S., 6x12¾ S.S.
4x9 C.S.
40 M.P.H.
FIG. 34
C_L
2.0
1.6
1.2
0.8
0.4
-0.4
-0.8
-12
-8
-4
4
8
12
16
20
24
28
α – DEGREES


DRAG COEFFICIENT VS. PITCH ANGLE
7x12¾ L.S., 6x12¾ S.S., 4x9 C.S.
40 M.P.H.
FIG. 35
C_D
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES


7×12¾ L.S., 6×12¾ S.S., 4×9 C.S.
40 M.P.H.
FIG. 36
STABILITY VS. α_{TRIM}
CONTROLLABILITY (α_{TRIM} VS. $\delta_{C.S.}$)
$-(dC_{M_{CG}}/d\alpha)_{TRIM}$
α_{TRIM} - DEGREES
0.12
0.08
0.04
12
8
4
-4
-8
-8
-4
4
8
12
16
20
24
28
32
$\delta_{C.S.}$, α_{TRIM} - DEGREES

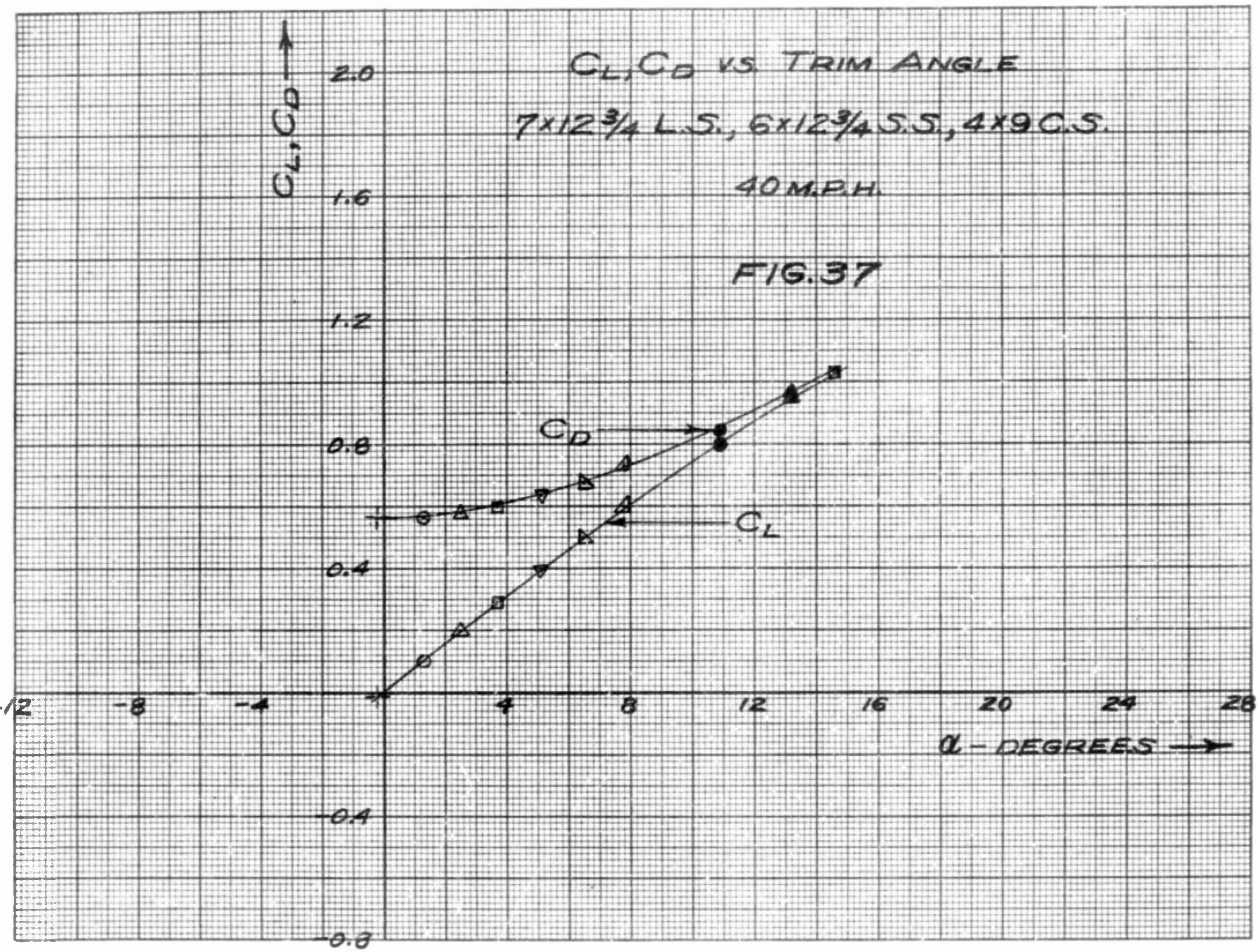

C_L, C_D VS. TRIM ANGLE
7×12¾ L.S., 6×12¾ S.S., 4×9 C.S.
40 M.P.H.
C_L, C_D
C_D
C_L
2.0
1.6
1.2
0.8
0.4
-0.4
-0.8
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES

FIG. 37

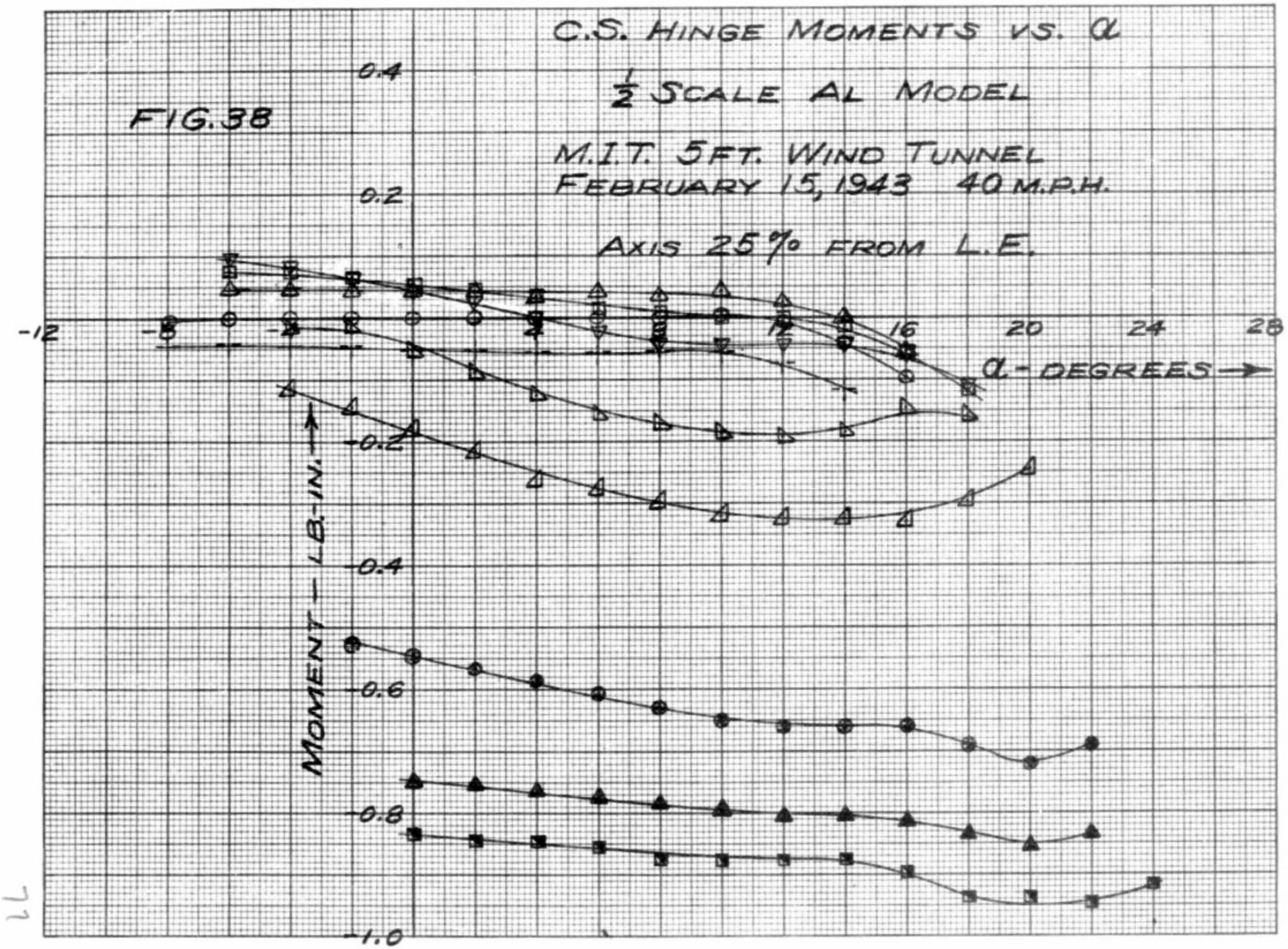


FIG. 38
C.S. HINGE MOMENTS VS. α
1/2 SCALE AL MODEL
M.I.T. 5 FT. WIND TUNNEL
FEBRUARY 15, 1943 40 M.P.H.
AXIS 25% FROM L.E.
α - DEGREES →
MOMENT - LB.-IN. →
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
-12
-8
-4
12
16
20
24
28

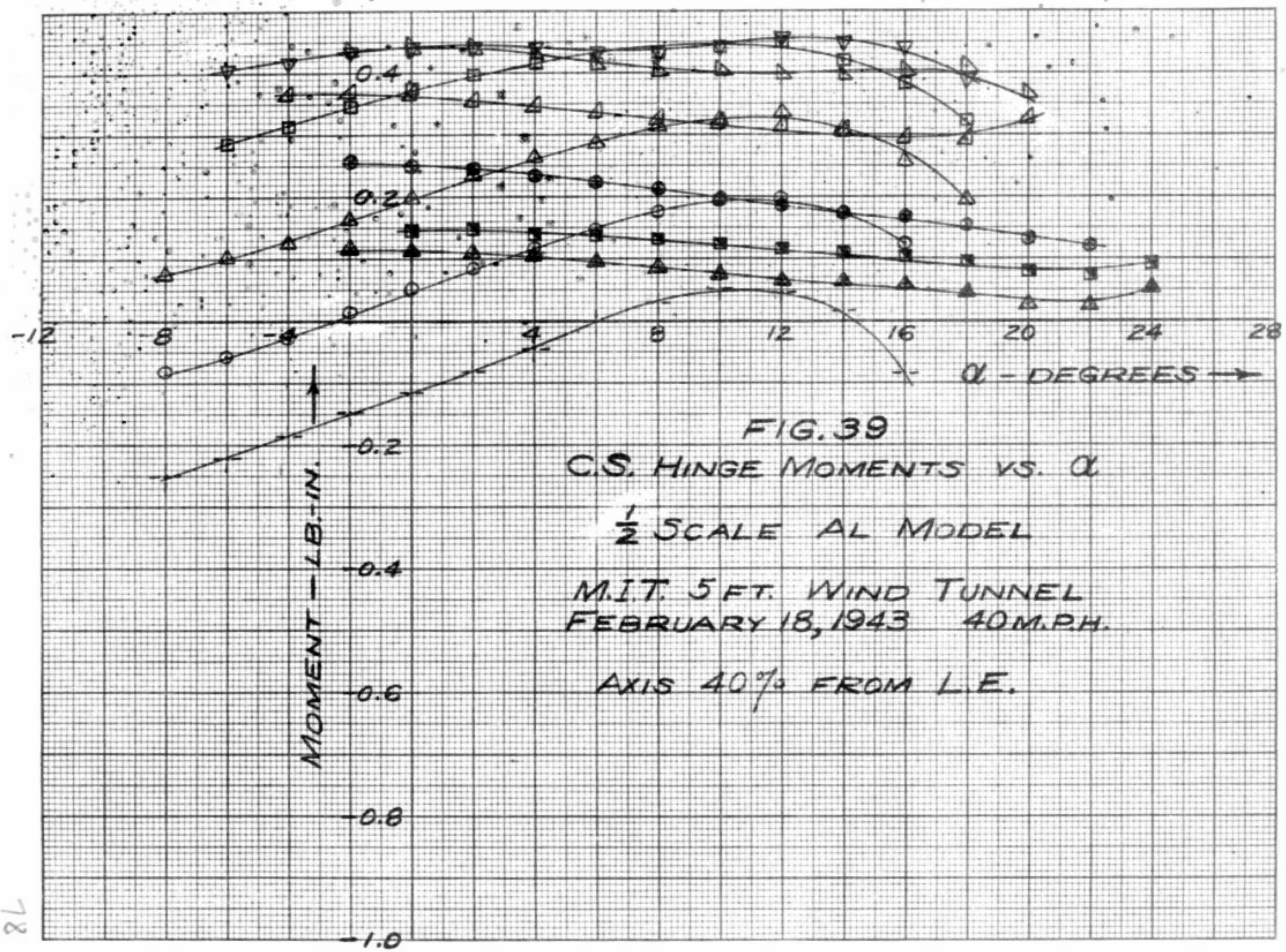


FIG. 39

C.S. HINGE MOMENTS VS. α

$\frac{1}{2}$ SCALE AL MODEL

M.I.T. 5 FT. WIND TUNNEL
FEBRUARY 18, 1943 40 M.P.H.

AXIS 40% FROM L.E.

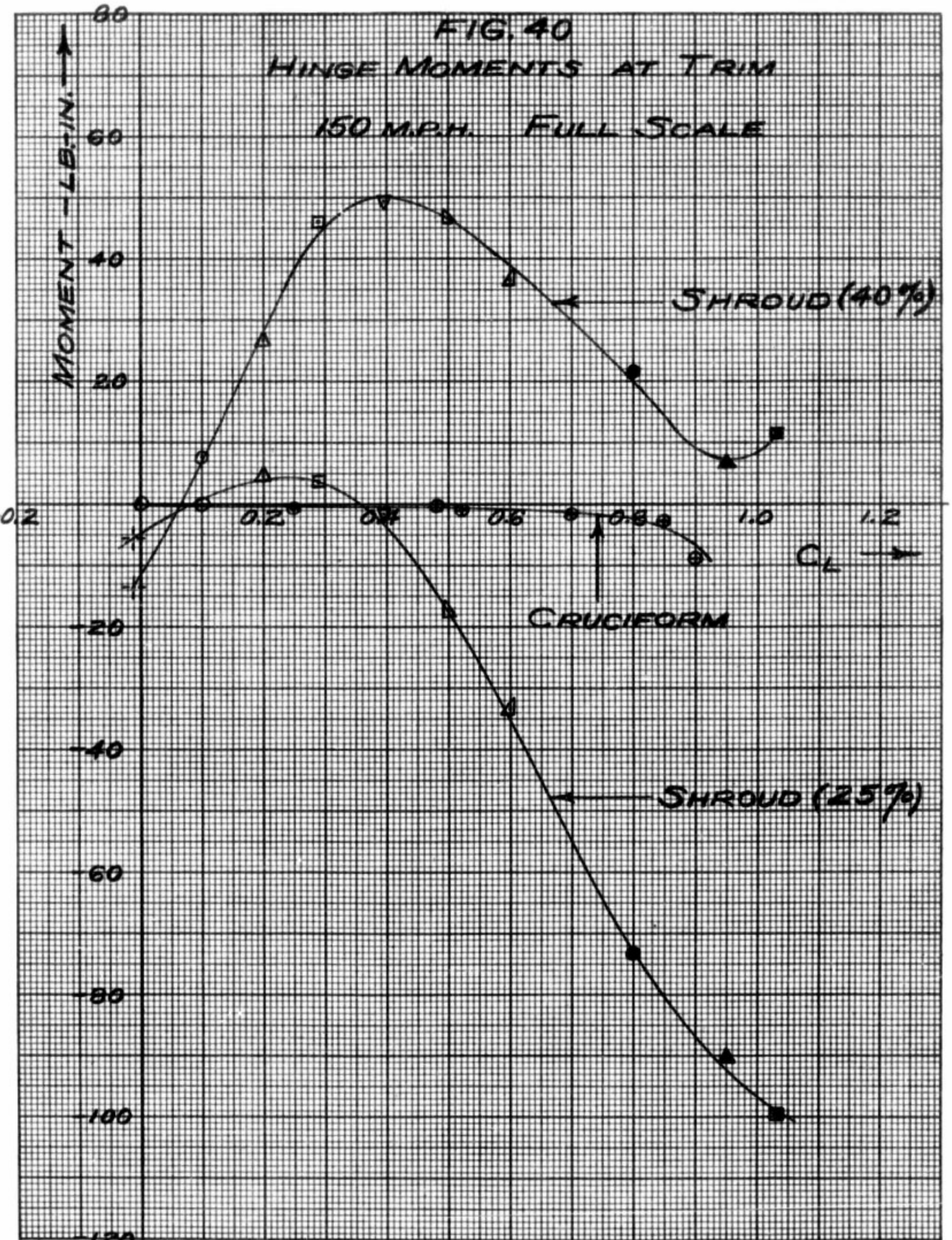


FIG. 40
HINGE MOMENTS AT TRIM
150 M.P.H. FULL SCALE
MOMENT - LB.-IN.
80
60
40
20
-20
-40
-60
-80
-100
-120
-0.2
0.2
0.4
0.6
0.8
1.0
1.2
C_L
SHROUD (40%)
SHROUD (25%)
CRUCIFORM

APPENDIX II. C. 2. PRELIMINARY TESTS: FIGS. 41 - 50.

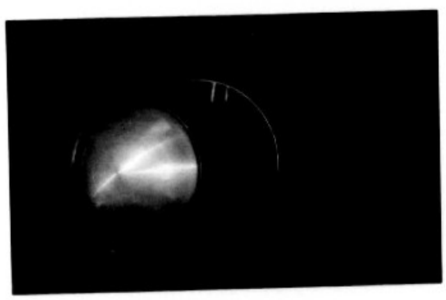


FIG. 41: DIRIGIBLE SHROUDED BOMB
with SPOILER PROJECTING OVER NOSE

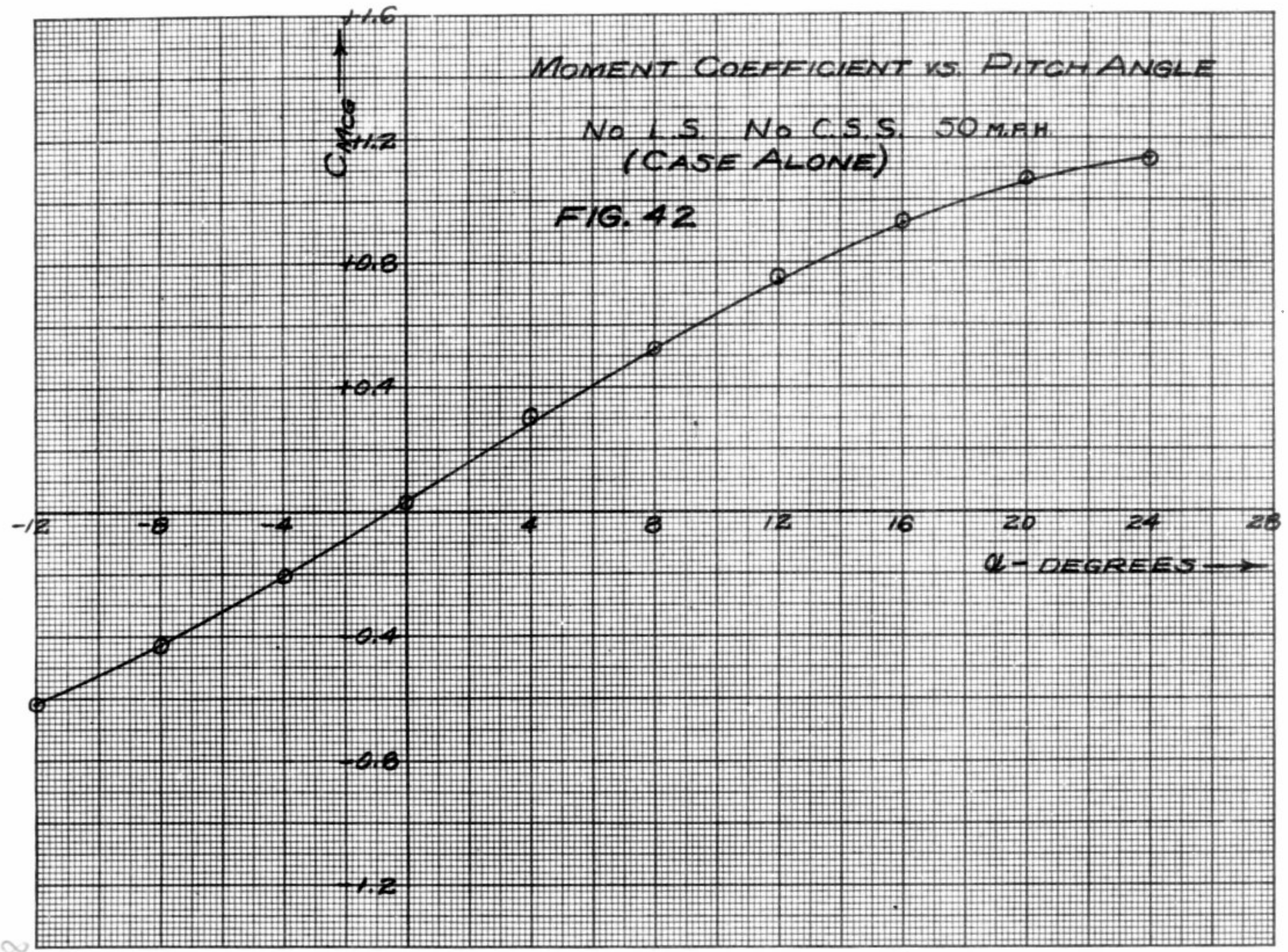
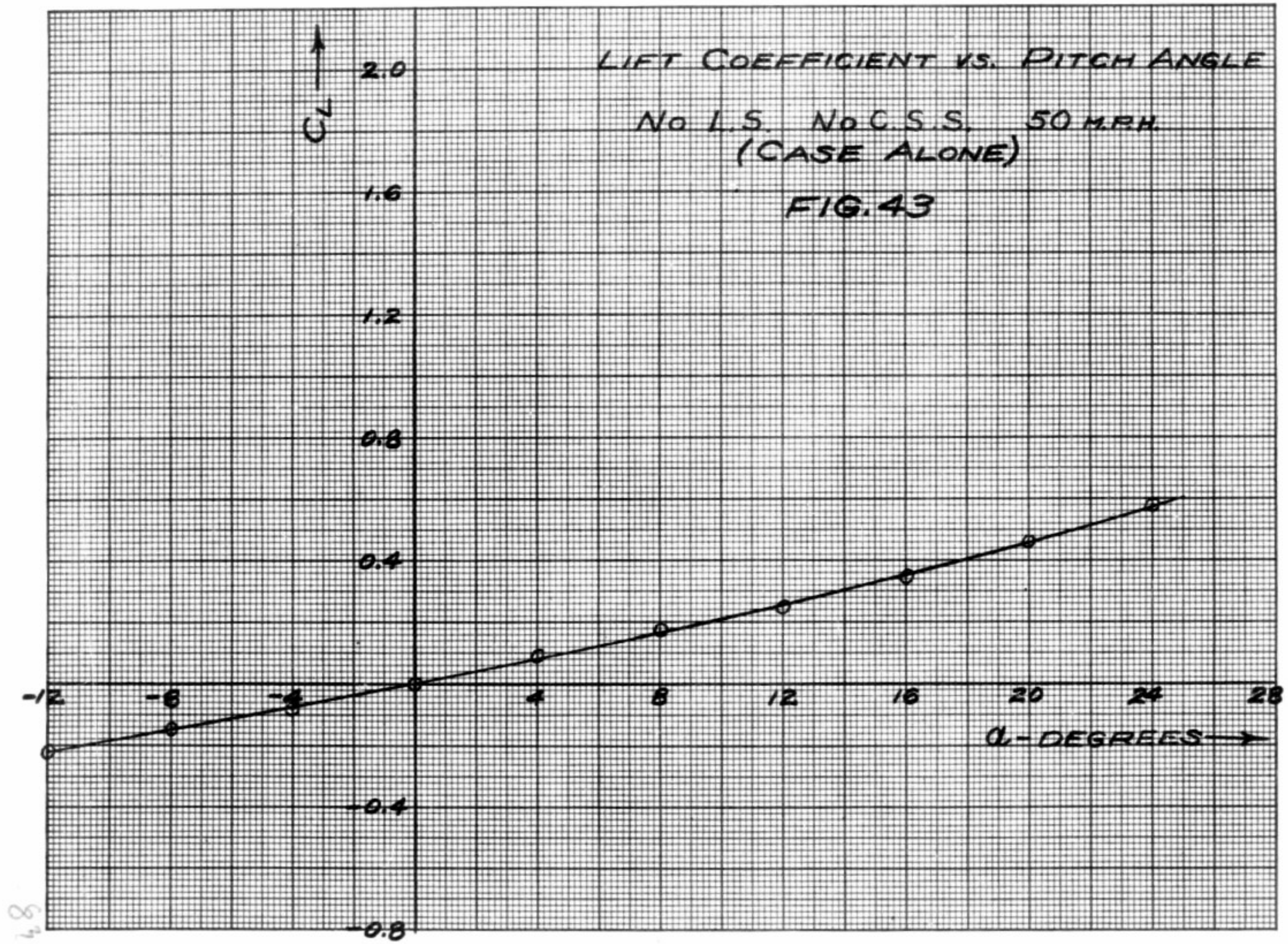

MOMENT COEFFICIENT VS. PITCH ANGLE
No L.S. No C.S.S. 50 M.P.H.
(CASE ALONE)
+1.6
+1.2
+0.8
+0.4
-0.4
-0.8
-1.2
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES

FIG. 42



LIFT COEFFICIENT VS. PITCH ANGLE
NO L.S. NO C.S.S. 50 M.P.H.
(CASE ALONE)
C_L
2.0
1.6
1.2
0.8
0.4
-0.4
-0.8
-12
-8
-4
4
8
12
16
20
24
28
a - DEGREES

FIG. 43

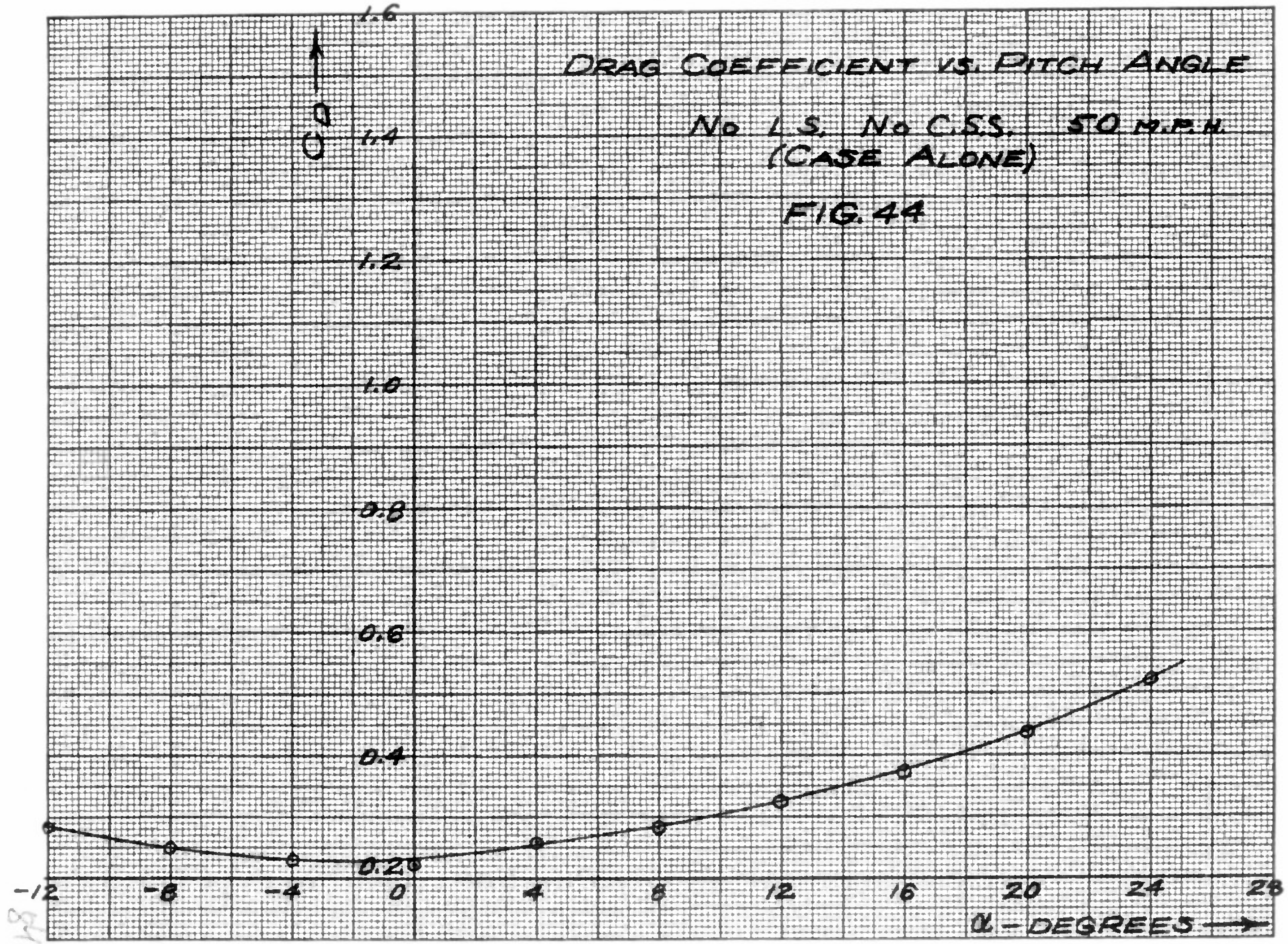
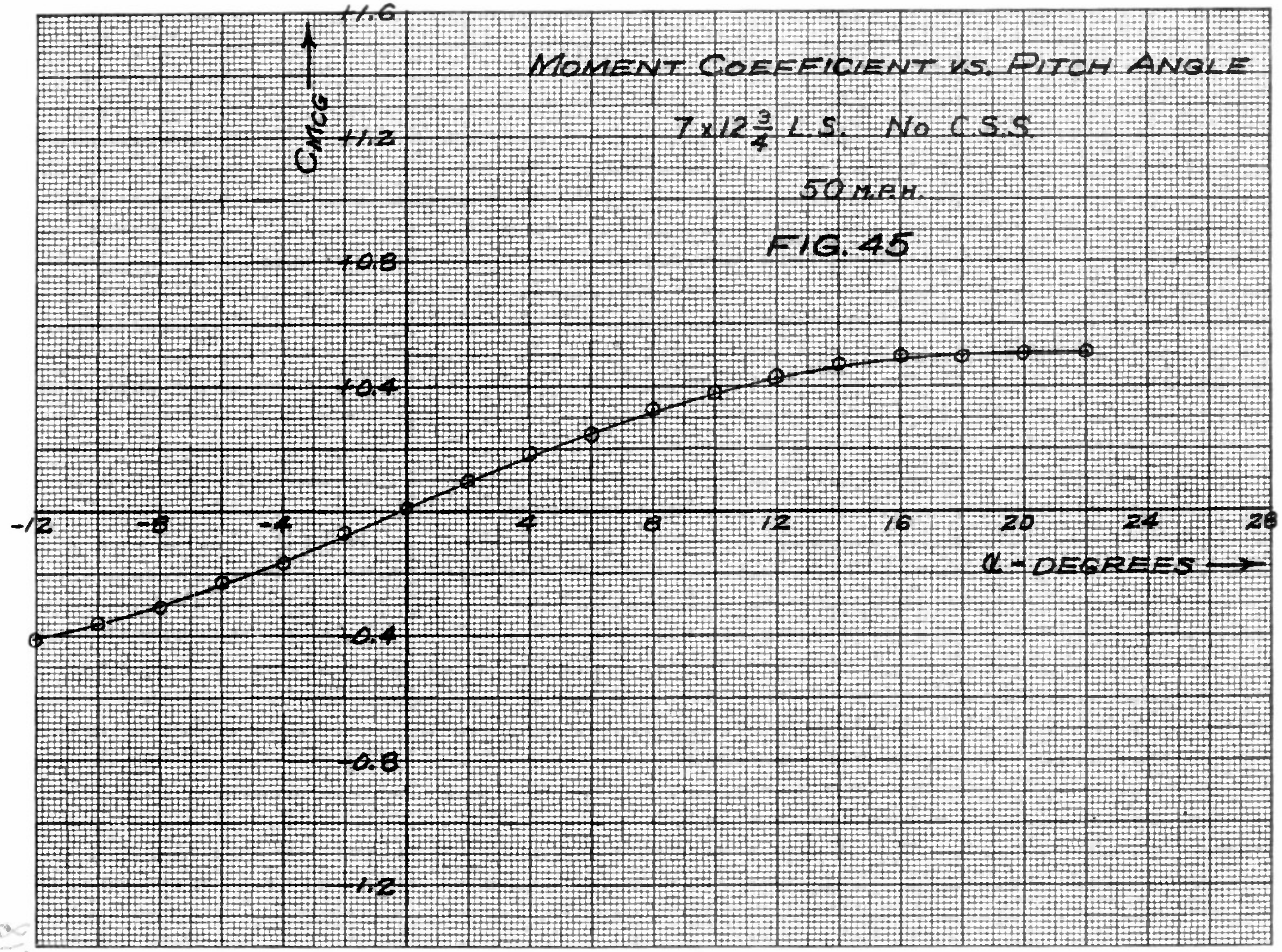
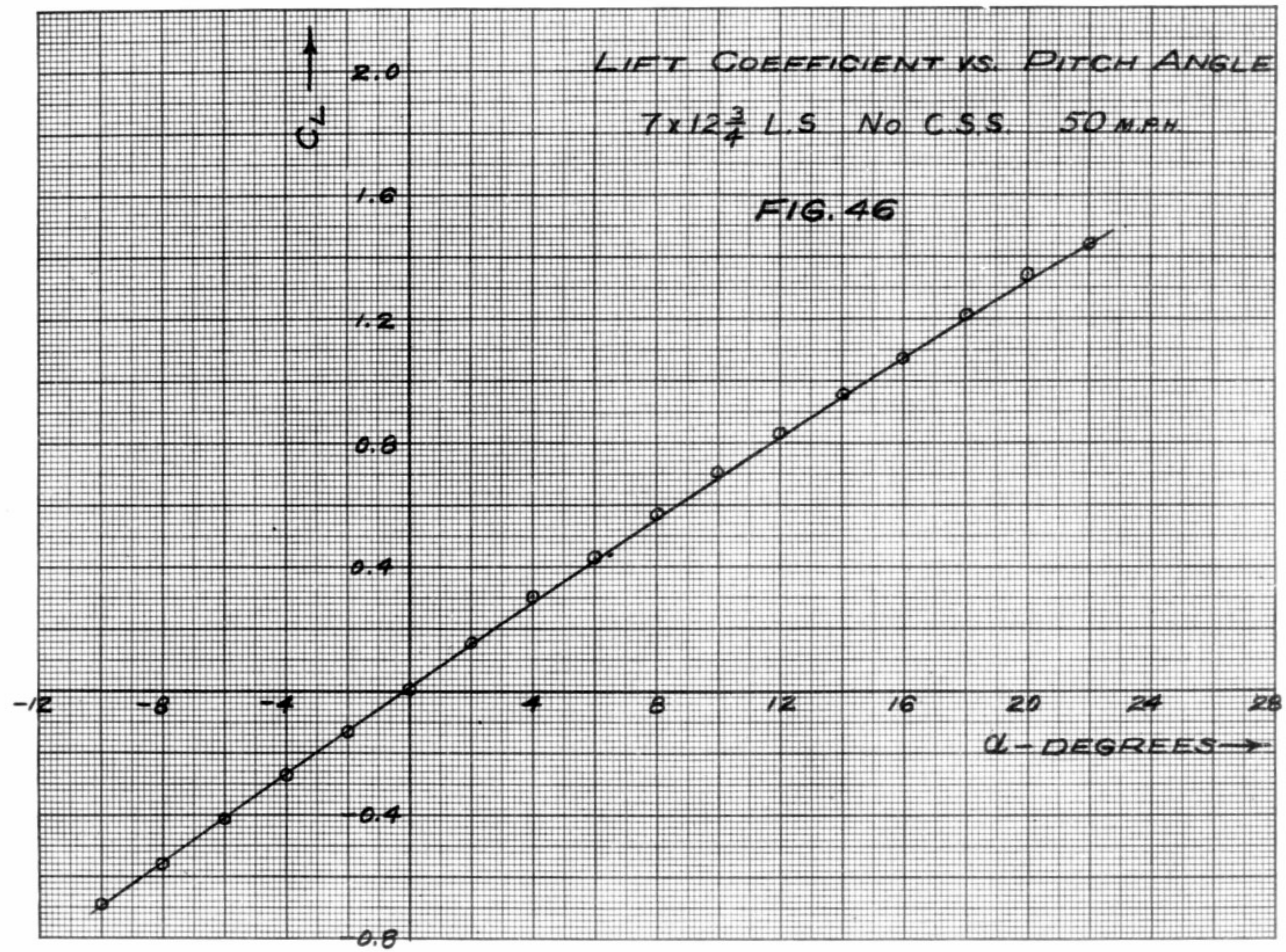

DRAG COEFFICIENT VS. PITCH ANGLE
NO L.S. NO C.S.S. 50 M.P.H.
(CASE ALONE)
C_D
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-12
-8
-4
0
4
8
12
16
20
24
28
α - DEGREES

FIG. 44



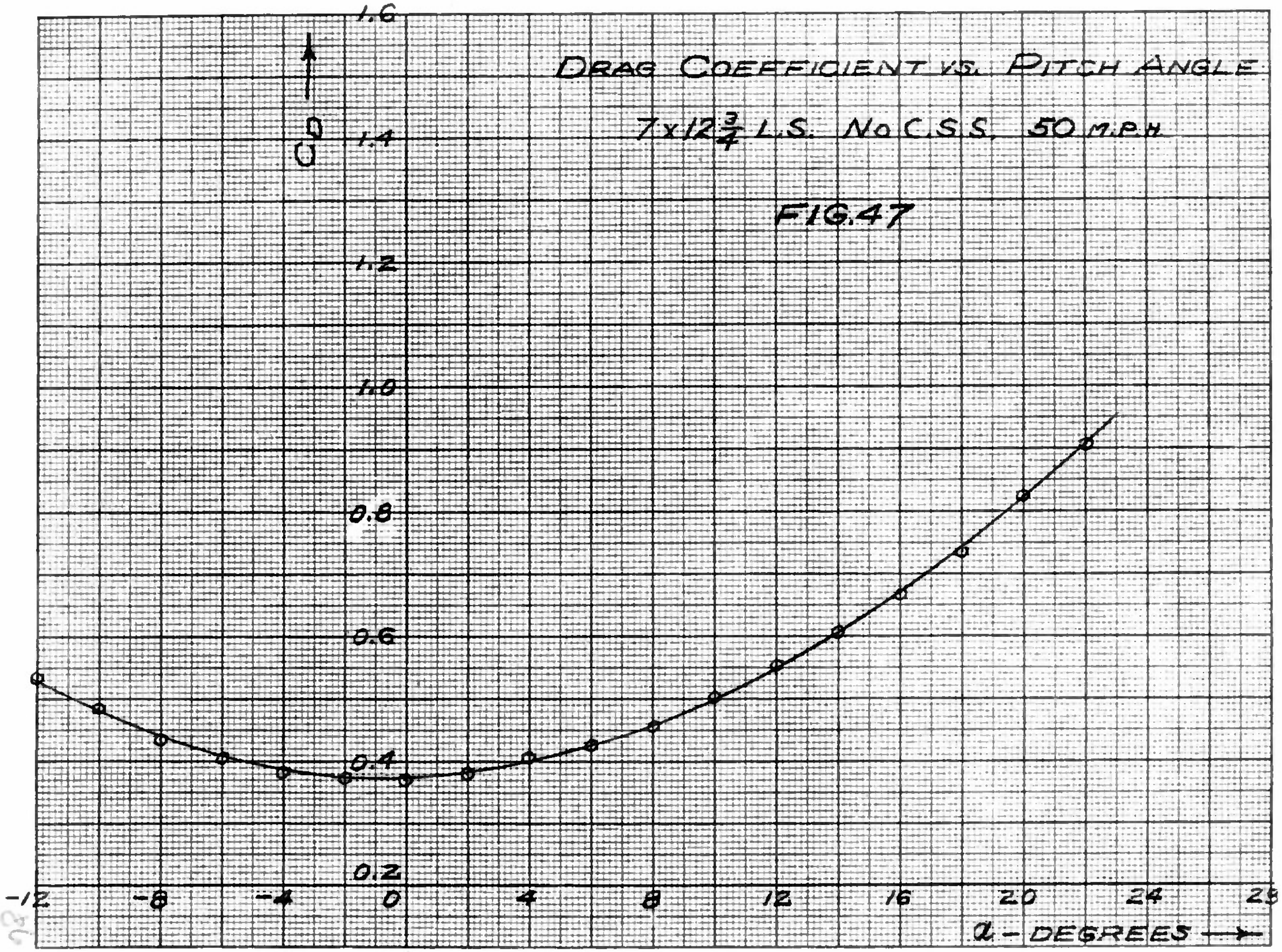
MOMENT COEFFICIENT VS. PITCH ANGLE
7 x 12 3/4 L.S. No C.S.S.
50 M.P.H.
C_{MCG}
+1.6
+1.2
+0.8
+0.4
-0.4
-0.8
-1.2
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES

FIG. 45



LIFT COEFFICIENT VS. PITCH ANGLE
7x12¾ L.S. No C.S.S. 50 M.P.H.
C_L
2.0
1.6
1.2
0.8
0.4
-0.4
-0.8
-12
-8
-4
4
8
12
16
20
24
28
α - DEGREES

FIG. 46



DRAG COEFFICIENT VS. PITCH ANGLE
7 x 12 3/4 L.S. No C.S.S. 50 M.P.H.
C_D
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-12
-8
-4
0
4
8
12
16
20
24
28
α - DEGREES

FIG.47

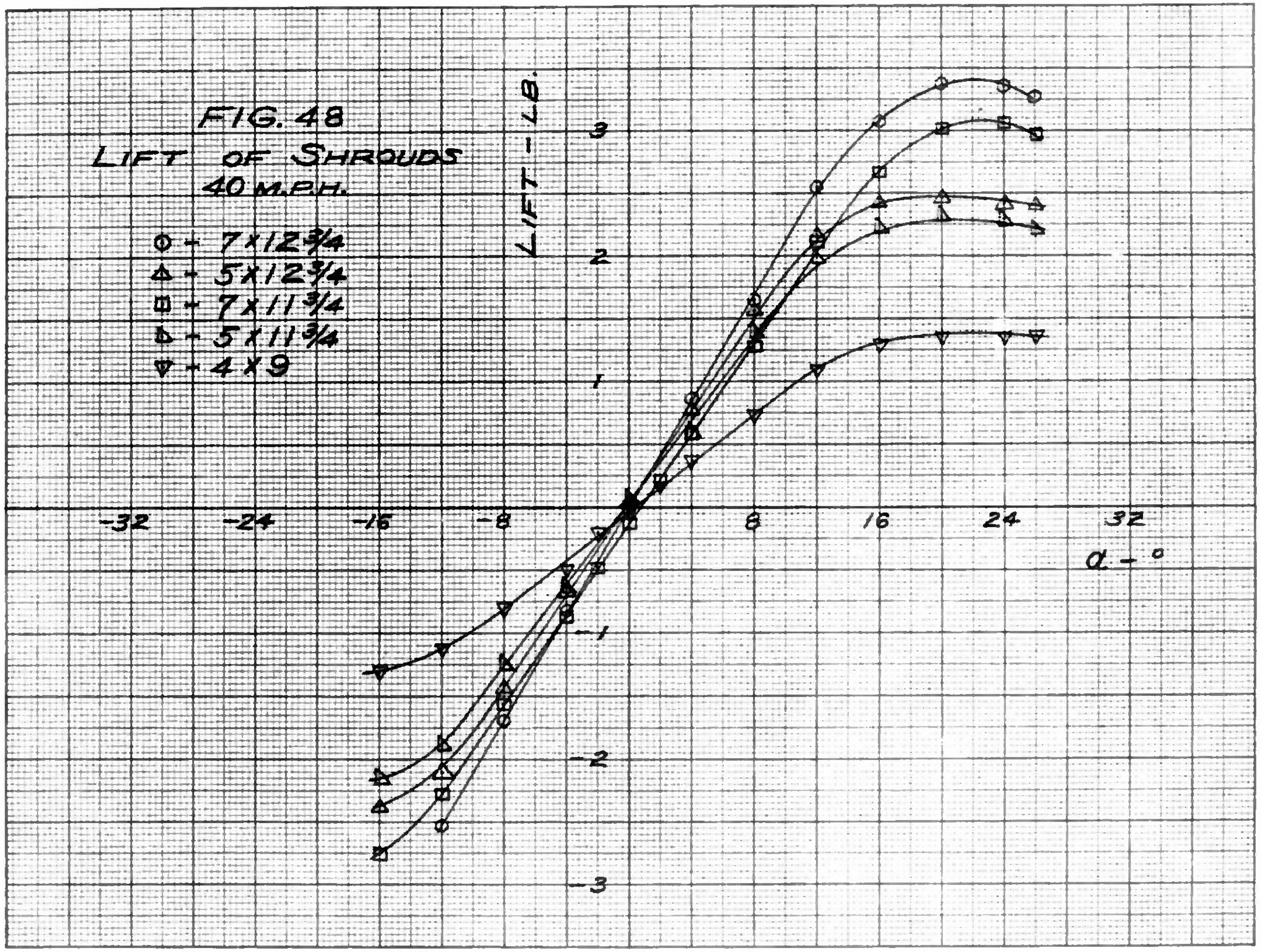


FIG. 48
LIFT OF SHROUDS
40 M.P.H.

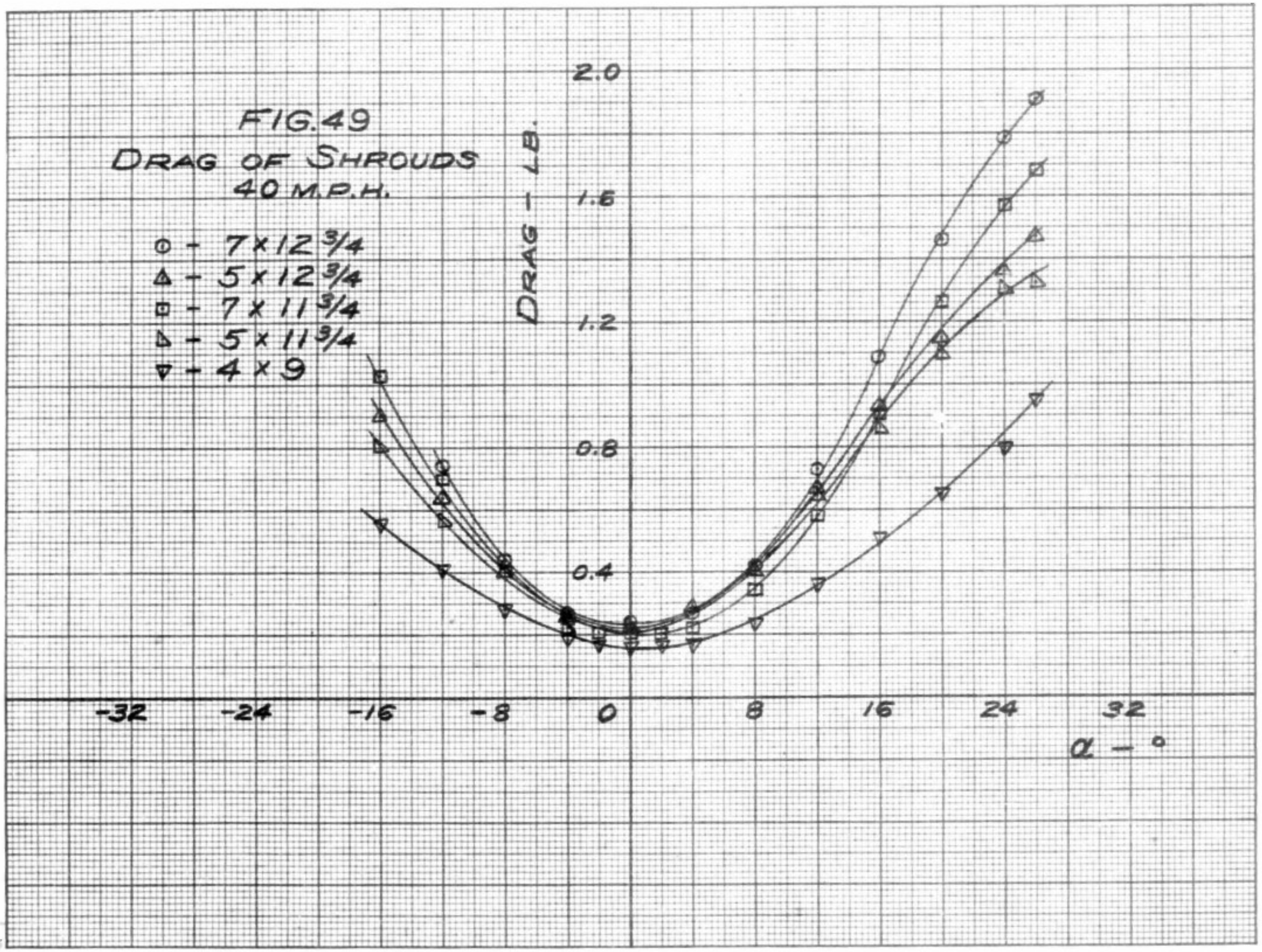


FIG. 49
DRAG OF SHROUDS
40 M.P.H.
⊙ - 7 x 12 3/4
△ - 5 x 12 3/4
□ - 7 x 11 3/4
◬ - 5 x 11 3/4
▽ - 4 x 9
DRAG - LB.
2.0
1.6
1.2
0.8
0.4
-32
-24
-16
-8
0
8
16
24
32
α - °

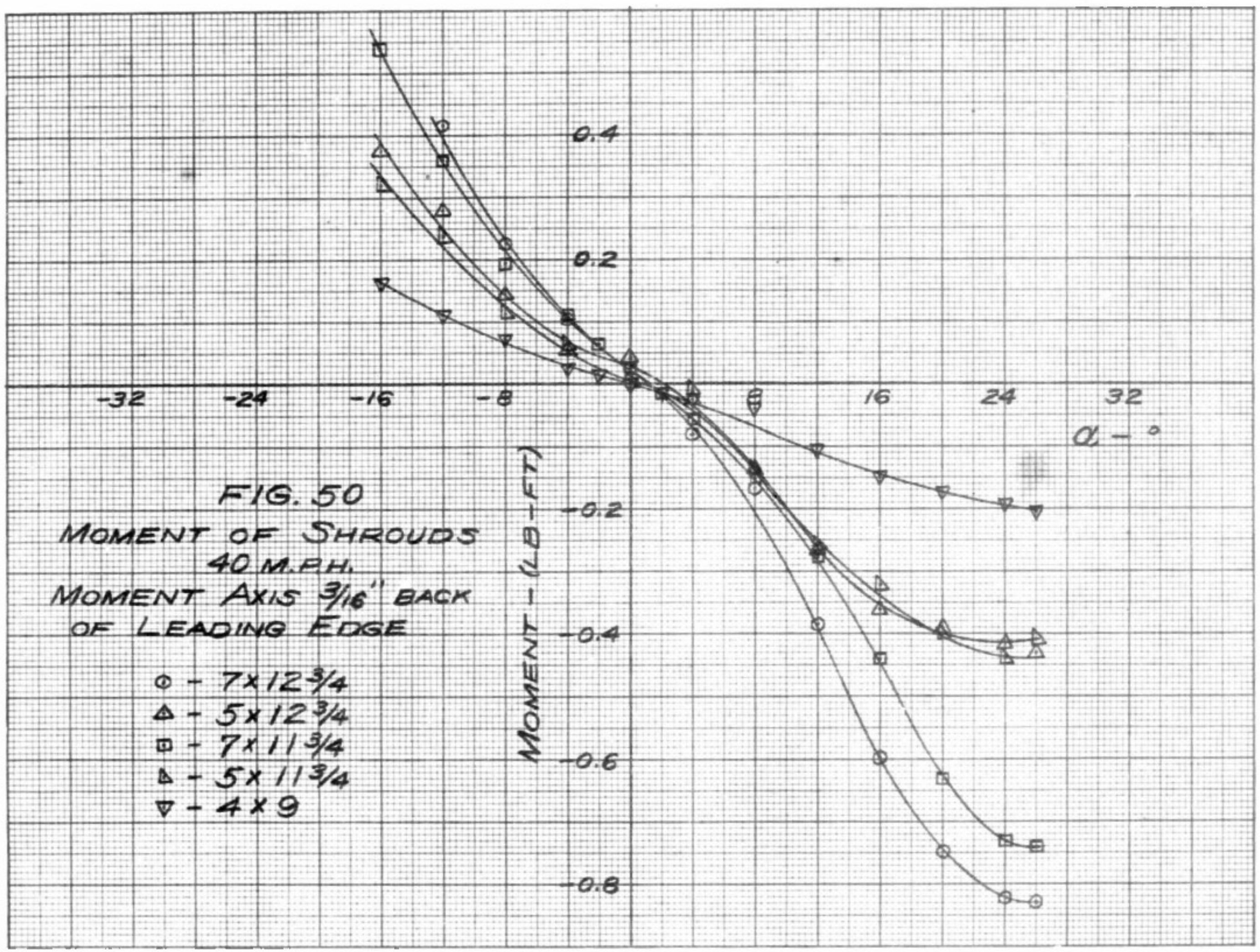


FIG. 50
MOMENT OF SHROUDS
40 M.P.H.
MOMENT AXIS 3/16" BACK
OF LEADING EDGE

REEL – C
67
A.T.I.

2076

TSDIN FORM 60 (13 MAR 47)

AUTHOR(S)		ATI- 2076
Hutzenlaub, J. F.	DIVISION: Guided Missiles (1) /2 SECTION: Aerodynamics and Ballistics (4) /1 CROSS REFERENCES: Wind tunnel testing - guided missiles (99100)	ORIG. AGENCY NUMBER PR 7 REVISION U

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FORG'N. TITLE:

ORIGINATING AGENCY: Massachusetts Institute of Technology Division of Industrial Cooperation, Cambridge, Mass.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U.S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Apr'43	89	52	photos, diagrs, graphs

P19/13

ABSTRACT

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Guided Bombs, Wind Tunnel Tests

R-1-4-6

ATI- 2076

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[illegible], J. F.

AUTHOR(S)

DIVISION: Guided Missiles (1)

SECTION: Aerodynamics and Ballistics (6)

CROSS REFERENCES: Wind tunnel testing - guided missiles (99100)

[illegible] 7

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